THE ELEMENTS

OF

CHEMISTRY
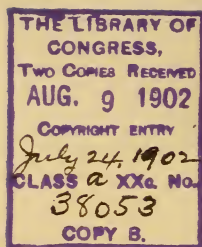
A TEXT-BOOK FOR BEGINNERS

BY

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President of the Johns Hopkins University

SECOND EDITION, REVISED

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PREFACE.

THIS book is written upon much the same plan as the Briefer Course in the same series. It is, however, materially simpler in many parts, and is in every way better adapted to younger pupils. In the opinion of the author a rational course in chemistry, whether for younger or older pupils, is something more than a lot of statements of facts of more or less importance; a lot of experiments of more or less beauty; or a lot of rules devised for the purpose of enabling the pupil to tell what things are made of. If the course does not to some extent help the pupil to think as well as to see, to reason as well as to observe, it does not deserve to be called rational. Not only must the pupil perform experiments, but he must know why he performs them, and what they teach. A good plan to follow is to talk over a certain part of the subject, showing how to construct the apparatus necessary for some of the experiments, and stating in a general way what is to be learned; then to let the pupil perform the experiments with the aid of the book and the teacher; and afterwards to make the experiments the basis for questioning. In this way the pupil will become observant, and at the same time he will discover when his experiments have been performed in the wrong way. It is better to go slowly at

first so as to allow the pupil time to become familiar with his surroundings and to enable him to learn how to work at the laboratory desk. A badly constructed piece of apparatus or an experiment badly performed in any way should not be allowed to pass. Experiments should be repeated as many times as may be necessary to secure accurate work.

Chemical theories are treated in a subordinate way, as it is believed that the attention should first be directed to the simpler facts of the subject and the methods by which these facts are learned. A brief statement of a few of the prevailing hypotheses is given in Chapter XIV. Whether it will be advisable for the pupils to spend any time in studying this chapter will depend upon their age and their mental attainments. If all they can do is to learn the statements by heart and repeat them without showing any signs of comprehension, then unquestionably the chapter should be omitted. It should be remembered that the object of the course laid down in this book is not to make chemists, but to help to develop sound minds, and at the same time to awaken interest in a set of natural phenomena of great importance to mankind. It is quite possible to teach the subject in such a way as to destroy all interest in chemical phenomena and to make the pupil shudder whenever a chemical formula is mentioned. There is no better way to accomplish the latter result than by giving prominence to incomprehensible theories and forcing the pupils to master a lot of equations which represent facts of which they are entirely ignorant.

Johns Hopkins University, December 27, 1886.

PREFACE TO SECOND EDITION.

This book has been thoroughly revised, and it is believed that all necessary or desirable changes have been made.

The author desires to thank Dr. C. E. Waters, of the Johns Hopkins University, for many valuable suggestions and for his conscientious reading of the proof.

I. R.

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APPARATUS AND CHEMICALS.

FOR the benefit of those who have no laboratory at command, and who may wish to make arrangements for going through with the experimental work, the following list has. been drawn up. In it is included everything necessary to perform the experiments on a small scale. Should it be desired to fit up a room with conveniences for students, the amount of apparatus necessary would depend upon the number of students, but for each individual the expense would be small, as many of the pieces of apparatus, such as the galvanic battery, burettes, weights, scales, etc., need not be multiplied. In place of some of the pieces of apparatus described in the book, ordinary kitchen utensils will answer: thus, for example, instead of the trough for collecting gases, a tin pan or a deep earthenware dish may be used; instead of the water-bath, a stew-pan, fitted with two or three different-sized tin or sheet-iron rings; and in place of glass cylinders for working with gases, wide-mouthed cheap bottles.

The publishers do not deal in chemicals and apparatus, nor, they may as well say, receive commissions on them. Any orders should be sent direct to the dealers.

Messrs. Eimer & Amend, Nos. 205 to 211 Third Avenue, New York, whom the publishers take the responsibility of recommending as thoroughly reliable, will furnish each of the following articles at the price given.

If several pieces of the apparatus in List No. 1 are taken, a discount of 10 per cent will be made; on a complete set 20 per cent discount will be allowed; on three or more sets, 25 per cent.

One or more of the articles in List No. 2, if not marked "net" or "10 per cent," will be supplied at 20 per cent discount if ordered with sets of the apparatus in List No. 1.

A discount of 10 per cent will be given on a complete set of the chemicals, and of 15 per cent on three or more sets.

For most items less than the whole set, there will have to be a small additional charge for packing. It should be realized, however, that usually the charge for packing one article must be as large as for several. Some articles can, of course, be mailed without any charge for packing.

LIST No. 1.

A list of apparatus and chemicals necessary for performing all of the experiments in Remsen's Elements of Chemistry, with the exception of experiments Nos. 34, 36, 46, 47, 48, 49, 51, 65, 66, 80, 81, and 113. To perform these latter experiments, the apparatus given in List No. 2 is required.

APPARATUS.

1 Nest Beakers, 1–3	$0 35
1 Jeweller's Blowpipe, 8 in	10
7 Wide-mouth Flint Bottles, two each, 2, 4, 8 oz., and one 32 oz.	40
1 Bunsen's Burner with regulator, or 6 oz. glass alcohol lamp, same price	40
1 5-in. U tube	25
1 Set Cork Borers, 1–6	1 00
1 Dropping-funnel, 50 c.c.	1 00
2 doz. Assorted Corks	20
1 Nest Hessian Crucibles, " threes "	5
2 1¼-in. Porcelain Crucibles	36
1 25 c.c. Grad. Cylinder	35
1 Deflagrating Spoon	15
1 each Evaporating Dish, 2½ and 3½ in	35
1 Lead Dish, 2 in	12
1 Round File, 5 in	20
1 Triangular File, 5 in	20
1 Pack White Filters, 4 in	13
4 Flasks : one 4 oz., two 8 oz., one 16 oz	65
1 Steel Forceps	20
2 Funnels, 2½ in	24
2 Funnel Tubes, one 10 in., one 15 in	25
1 Gas Bottle, 8 oz., with 2-hole R Stopper	30
½ lb. Assorted Glass Tubing, 4–7	25
¼ lb. Assorted Glass Rods	15
2 Sheets each Red and Blue Litmus-paper	20
1 Horseshoe Magnet, 3 in	12
1 Porcelain Mortar and Pestle, 3½ in	45
1 Piece Platinum Foil, 1 × 1½ in.	1 00
6 in. Medium Platinum Wire	50
1 Plain Retort, 8 oz	22

1 Stoppered Retort, 16 oz	$0 45
3 ft. Rubber Tubing for gas, ¼ in. (Only needed if Bunsen's Burner is used.)	39
2 ft. Rubber Tubing (for connections)	20
1 3½ in. Sand Bath	15
1 Hand Scale, with weights	85
1 Test Tube Stand	30
12 Test Tubes, 5 in	30
1 Test Tube Brush	5
1 Test Tube Clamp	15
1 Iron Tripod	30
1 Filter-stand (2 rings)	45
1 Wire Triangle	5
1 Piece Wire Gauze, 6 × 6 in.	10
1 Piece Blue Glass, 2 × 2 in	10
1 Piece Ground Glass, thin, 4 × 4 in	6
2 2-in Watch-glasses	10
1 5-in. Water-bath	90
2 Wire Clamp Supports	1 60
	$16 64

CHEMICALS.

4 oz. Acid Acetic, pure (bottle 5 cents extra)	$0 10
4 oz. Acid Arsenious	10
16 oz. " Hydrochloric (bottle 15 cents extra)	10
8 oz. Acid Nitric (bottle 12 cents extra)	10
2 oz. Acid Oxalic	10
16 oz. " Sulphuric (bottle 12 cents extra)	10
1 oz. Acid Tartaric	10
2 oz. Alcohol, for experiments only (bottle 4 cents extra)	10
8 oz. Alum	10
4 oz. Ammon. Chloride	10

8 oz. Ammon. Hydrate, concentrated (bottle 10 cents extra).$0 10
4 oz. Ammon. Nitrate   10
2 oz. Antimony, powdered.......   10
2 oz.   "   and Potassium Tartrate.....................   20
2 oz. Barium Chloride............   10
4 oz. Calcium Chloride, fused.. .   10
1 oz.   "   Carbide (bottle 3 cents extra)............ . ..   10
4 oz.   "   Sulphate..........   10
4 oz. Carbon Bisulphide (bottle 5 cents extra)...............   10
8 oz. Animal Charcoal, powdered   10
8 oz. Copper Foil................   20
4 oz.   "   Sulphate..........   10
1 oz.   "   Oxide............   15
4 oz. Fluor spar, powdered......   10
1 oz. Indigo   10
1 oz. Iodine (bottle 2 cents extra)   30
4 oz. Iron Filings, fine..........   10
8 oz. "   Sulphide.............   10
4 oz. "   Sulphate...   10
4 oz. Lead Sheet.................   10
4 oz.   "   Acetate   10
2 oz.   "   Nitrate.............   10
1 oz.   "   Peroxide...........   10
2 oz.   "   Sesquioxide.........   10
1 oz. Litmus...................   10
½ dram Magnesium Ribbon......   10
1 lb. Manganese Dioxide, powdered.......................   10
1 oz. Mercury Red Oxide...   10

1 oz. Nutgalls, powdered........$0 10
2 oz. Paraffin....   10
1 oz. Phosphorus (bottle 10 cents extra)......................   15
1 dram Potassium.......   30
2 oz.   "   Bromide......   10
4 oz.   "   Carbonate (bottle 5 cents extra)........   10
4 oz. Potassium Chlorate   10
4 oz.   "   Bichromate.....   10
2 oz.   "   Ferricyanide....   10
4 oz.   "   Hydrate Sticks (bottle 5 cents extra)........   20
1 oz. Potassium Iodide (bottle 5 cents extra)   25
4 oz. Potassium Nitrate..........   10
2 oz.   "   Permanganate..   10
1 dram Sodium (bottle 3 cents extra)   10
2 oz. Sodium Acetate, fused.....   10
2 oz.   "   Bicarbonate..... ..   10
4 oz.   "   Biborate (Borax)..   10
4 oz.   "   Hydrate (bottle 5 cents extra)..................   20
4 oz. Sodium Nitrate............   10
4 oz.   "   Sulphate...........   10
8 oz. Sulphur, roll....   10
4 oz. Tin, granulated............   10
16 oz. Zinc, granulated..........   20
2 oz.   "   Sulphate............   10
                                   ———
                                   $8 36

LIST No. 2.

In order to perform experiments Nos. 34, 36, 46, 47, 48, 49, 51, 65, 66, 80, 81, 113, the following additional apparatus is necessary:

2 qt. Bunsen's Cells (10 p. c.) ...$2 20
2 Platinum Plates,1 × ½ inch (net)   40
1 Charcoal Furnace, 18 in. (20 p. c.)........ .... 2 50
    or 1 Charcoal Furnace, 24 in. (20 p. c.), $3.00, or 1 10-burner Gas Combustion Furnace (20 p. c.), $20 00.
1 25-in. hard Glass Tube, 1 in. bore (10 p. c.)................ 1 00
    or 1 25-in. Porcelain Combustion Tube, 1 in. bore (20p. c.), $1 75.
3 pt. Woulff's Bottles, 2-necked (20 p. c.)............ .... 1 50
1 hard Glass Tube, drawn out, 12 × ½ in. bore (net)..........   25

1 Oxyhydrogen Blowpipe (20 p. c.)......................$5 50
2 Gasholders for Oxygen and Hydrogen, 5 gal. (20 p. c.)... 30 00
1 Liebig's Condenser, 15 in. (20 p. c.)......................... 1 10
2 Burettes, 50 c.c. $\frac{1}{10}$ (20 p. c.).....2 70
2 Pinchcocks (20 p. c.)............   30
1 Copper Air-bath, 6×8 in. (20 p. c.)...................... 4 50
1 Kellog-Bunsen's Vapor Lamp, complete (a substitute in case gas is not used as fuel) (net). 10 00
                                   ———
                                   $61 95

THE ELEMENTS OF CHEMISTRY.

CHAPTER I.

CHEMICAL CHANGES—PHYSICAL CHANGES

Some Familiar Changes.—You are all familiar with many changes which are taking place in the things around you. Take, for example, the changes which are called *fire*. You see substances destroyed by fire. They disappear. You feel the heat produced by the burning. You know that some things will burn and others will not. Again, you all know that iron when exposed to the air is changed, becoming covered with a reddish-brown substance called *rust*. If fruit-juices or milk be allowed to stand in contact with the air they become sour. If a spark comes in contact with gunpowder there is a flash and the powder disappears, dense smoke appearing in its place.

Changes of Another Kind.—If a piece of stone or of iron is brought in contact with something hot it becomes hot itself. If taken away it becomes cool again. If heated very hot it gives light. When, for example, iron becomes "red-hot" we can see it in a dark room. Iron may also be changed by contact with loadstone. After it has been rubbed with loadstone it has the power to attract and hold

to itself other pieces of iron.   When a solid body is struck
with another solid a sound is produced.   At a low tem-
perature water is solid, forming ice.   If the ice becomes
warm enough it melts and becomes water.   If the water
is heated high enough it becomes steam.   By cooling steam
it changes to water, and by cooling water it changes to ice.

Two Kinds of Change.—When a substance burns it
becomes something entirely different.   Iron-rust is not
iron.   Sour milk is not fresh milk.   Gunpowder after the
flash is not gunpowder.   In these cases, then, the sub-
stances that are changed disappear and something else is
formed in their place.   On the other hand, when a piece
of iron that is hot is allowed to cool it is the same thing
that it was before it was heated.   Red-hot iron soon ceases
to give light if it is taken away from the fire.   Water may
be cooled down and changed to ice, and the ice heated and
changed to water; and the water formed from the ice is
exactly the same thing as the water from which the ice
was formed.   In these cases the substances are not per-
manently changed.   You see thus that we have two classes
of changes presented to us for study:

1st. Those which do not affect the composition of sub-
stances.

2d. Those which affect the composition of substances
and give rise to the formation of new substances with new
properties.

Changes of the first kind are called *physical changes*.
Those of the second kind are called *chemical changes*.

Physics and Chemistry.—That branch of knowledge
which has to deal with physical changes is known as
PHYSICS; and that which has to deal with chemical changes

is known as CHEMISTRY. Everything that has to do with motion, with heat, light, sound, electricity, and magnetism, is studied under the head of Physics. Everything that has to do with the composition of substances and changes in the composition is studied under the head of Chemistry.

All Physical and Chemical Changes are Related.— Although at first sight the different kinds of change already mentioned appear to be quite distinct from one another, they are in reality closely related. If a body in motion is suddenly stopped it becomes hot. Many examples of a similar change of motion into heat are familiar: a wire becomes hot when hammered on an anvil; a coin rubbed on cloth becomes hot. In both cases the cause of the heat is the interference with the motion. The hammer is stopped and becomes hot; the coin is not stopped, but the motion is interfered with, and we have to push harder in order to move it over the cloth than we should to move it in the air. Again, we know that by means of heat we can produce motion. The steam-engine is the best example of this. We build a fire; this heats the water in the boiler; the water is converted into steam, which expands and moves the piston, and the motion of the piston is the seat of all the complex motions that are found in the different parts of the engine. The train or ship moves. What moves it? Plainly, the heat is the cause of the motion. But we can go a step farther back and ask what causes the heat. The answer is clear. It is the burning of the fuel. But, in burning, the composition of the fuel is completely changed. When a piece of coal burns, then, its composition is changing, and as a result of this change

heat is produced.   The heat is, therefore, produced by a chemical change in the coal, and the motion of the steam-engine is the result of the chemical change taking place in the coal or wood which, in burning, produces the heat.

Heat Causes Chemical Change.—Just as chemical change produces heat, as in the burning of a piece of wood, so heat causes chemical changes.

EXPERIMENT 1.—In a clean, *dry* test-tube put enough white sugar to make a layer ¼ to ½ inch thick.   Hold the tube in the flame of a spirit-lamp or a laboratory burner as shown in the figure, and heat until no more fumes are given off.   What changes take place?   What do you notice on the sides of the tube?   What remains behind?   What is its color and taste?   Does it dissolve in water?   Is it sugar?   Is the change which has taken place chemical or physical?   What caused it?
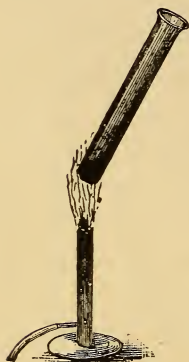
FIG. 1.

EXPERIMENT 2.—From a piece of glass tubing of about ¼ inch internal diameter cut off a piece about four inches long by making a mark across it with a triangular file, and then seizing it with both hands, one on each side of the mark, pulling and at the same time pressing slightly as if to break it.   Clean and dry it, and hold one end in the flame of a laboratory burner until it melts together.   During the melting twirl the tube constantly between the finger and thumb so that the heat may act uniformly upon it.   After it has cooled down put into it enough red oxide of mercury (mercuric oxide) to form a layer ½ inch thick.   Heat the tube as in the last experiment.—What change in color do you notice?   What is deposited on the sides of the tube?   During the heating insert a splinter of wood with a spark on the end into the tube.   What follows?   Take it out and put it back a few times.   Is there any difference between the burning in the tube and out of it?   What difference?   How do you know that the red substance which you put into the tube has been changed?   Is the change chemical or physical?   What caused the change?

Chemical Change Caused in Other Ways.—In the two experiments just performed heat caused chemical change. Chemical changes can be produced in other ways. The simplest way is by bringing substances together.

EXPERIMENT 3.—Examine a piece of calc-spar or marble. Notice whether it is hard or soft. Heat a small piece in a glass tube such as used in Experiment 2. Does it change in any way? Does it dissolve in water? In order to learn whether a substance is soluble in water proceed as follows : Put a piece about the size of a pea in a test-tube with distilled water. Thoroughly shake, and then, as heating usually aids solution, boil. Now pour off a few drops of the liquid on a piece of platinum-foil * or a watch-glass, and by gently heating cause the water to pass off as steam. If there is anything solid in solution there will be something solid left on the platinum-foil or watch-glass. If not, there will be nothing left.—Knowing now the general properties of the calc-spar or marble you will be able to determine whether it is changed or not. Treat a small piece with dilute hydrochloric acid. What takes place? After the action has continued for about half a minute insert a lighted match in the upper part of the tube. Does the match continue to burn? Does the substance in the tube burn? Is the invisible substance in the upper part of the tube ordinary air? Why not? Does the solid substance disappear? In order to tell whether it has been changed chemically the hydrochloric acid

FIG. 2.

must be got rid of. This can be done by boiling it, when it passes off in the form of vapor, just as water does, and then whatever is in solution will remain behind. For this purpose put
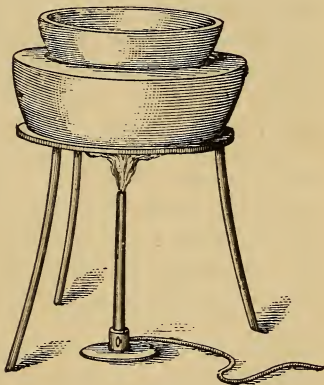
* The expensive metal platinum is much used in chemical laboratories, for the reason that it is not easily changed chemically by heat or by most substances used in the laboratory.

the solution in a small, clean porcelain evaporating-dish, and put this on a vessel containing boiling water, or a water-bath. The operation should be carried on in a place where there is a good draught, so that the vapors will not collect in the working-room. They are not poisonous, but they are annoying. The arrangement for evaporating is illustrated in Fig. 2. After the liquid has evaporated and the substance in the evaporating-dish is dry, examine it and carefully compare its properties with those of the substance which was put into the test-tube. Is it the same substance? Is it hard or soft? Does it change when heated in a tube? Is there an appearance of bubbling when hydrochloric acid is poured on it? Does it dissolve in water? Does it change when allowed to lie in contact with the air?

EXPERIMENT 4.—Bring together in a test-tube a small piece of copper and some moderately dilute nitric acid. Hold the mouth of the tube away from your face and do not inhale the vapors. What is the appearance of the vapors given off? What is the appearance of the liquid in the tube? Does the copper dissolve? Examine the solution, as in the preceding experiment, and see what has been formed. What are the properties of the substance found after the liquid has evaporated? Is it colored? Is it hard or soft? Does it change when heated in a tube? Is it soluble in water? Does it in any way suggest the copper with which you started?

EXPERIMENT 5.—Try the action of dilute sulphuric acid on a little zinc in a test-tube. An invisible gas will be given off. Hold the thumb loosely over the mouth of the tube, and after a few moments apply a lighted match to the mouth. What takes place? After the zinc has disappeared evaporate the solution as before. Carefully compare the properties of the substance left behind with those of zinc.

EXPERIMENT 6.—Hold the end of a piece of magnesium ribbon about eight inches long in a flame until it takes fire. Then hold the burning substance quietly over a piece of paper, so that the light, white substance which is formed may fall upon the paper. If the paper is dark the product can be seen more readily. Compare the properties of this product with those of magnesium.

EXPERIMENT 7.—In a small dry flask of about four ounces capacity put a bit of granulated tin or of pure tin-foil. Pour

upon it enough concentrated nitric acid to cover it. If no change takes place at first, heat gently, and presently you will have evidence that change is taking place. Is there anything in this experiment that suggests Experiment 4 ? What does the substance that is left behind after the action is finished look like ? Compare the properties of the product with those of tin.

Solution Aids Chemical Action. — In the cases just studied it was only necessary to bring the substances together, when they acted at once. In each case one of the substances used was a liquid. Solids do not, as a rule, act upon one another as readily as liquids act upon solids.

EXPERIMENT 8.—Mix together in a dry mortar a little dry tartaric acid and about an equal quantity of dry bicarbonate of soda (sodium bicarbonate). Do you see any evidence of action ? Now dissolve a little tartaric acid in water in a test-tube, and a little bicarbonate of soda in water in another test-tube. Pour the two solutions together. What evidence have you now that action takes place ? Pour water upon the dry mixture first made. Does action take place ? What causes the bubbling ? Will a match burn in the gas ? In which experiment already performed was a similar gas obtained ?

EXPERIMENT 9.—Mix together in a dry mortar a little dry sulphate of iron (green vitriol) and a little dry ferricyanide of potassium (red prussiate of potash). Does action take place ? Make a dilute solution of each of the two substances and pour them together. What evidence have you that action takes place? Pour water on the dry mixture. Does action take place ?

Summary.—From the experiments it will be seen (1) that heat causes chemical change; (2) that in some cases simple contact of substances is sufficient to cause chemical change; (3) that solution aids chemical change. In all the cases of chemical action thus far studied one thing was observed, viz., that the substances which were acted upon lost their own properties and new substances were formed. This is true in all cases of chemical action, and the truth may be stated thus:

Whenever two or more substances act upon one another chemically they lose their own properties, and new substances are formed with entirely different properties.

Difference between Combining Chemically and simply Mixing.—By mixing is meant bringing things together closely, so that the particles of one shall be in contact with the particles of the other. We mix salt and sugar by putting them together in a vessel and shaking them, or by stirring as with a pestle in a mortar. The longer we stir the more closely the substances are brought together. But no matter how long we may stir the mixture, it remains a mixture and contains both sugar and salt. In some cases, by stirring, chemical action can be brought about, but generally not.

EXPERIMENT 10.—Mix two or three grams of dry powdered roll-sulphur and an equal weight of very fine dry iron filings in a small dry mortar. Examine a little of the mixture with a microscope. Can you distinguish the particles of sulphur and those of iron? Pass a small magnet over the mixture. Are particles of iron drawn out of the mixture? Has chemical action taken place?

EXPERIMENT 11.—*Caution! Carbon bisulphide or bisulphide of carbon takes fire easily. In working with it keep away from flames.*—Pour two or three cubic centimetres of bisulphide of carbon on a little powdered roll-sulphur in a dry test-tube. Does the sulphur dissolve? Treat iron filings in the same way. Does the iron dissolve? Now treat a small quantity of the mixture prepared in Experiment 10 with bisulphide of carbon. After the sulphur is dissolved pour off the solution in a good-sized watch-glass and let it stand. Examine what is left in the test-tube. Is it iron? After the liquid has evaporated examine what is left on the watch-glass. Is it sulphur?

EXPERIMENT 12.—Mix three grams of finely powdered roll-sulphur and three grams of fine wrought-iron filings or powdered iron to be had of the druggists. Put the mixture in a dry test-tube. Heat gently at first and notice the changes. At first the

sulphur melts and becomes dark-colored. It may even take fire. But soon something else takes place. The whole mass begins to glow, and if you at once take the tube out of the flame the mass will continue to glow, becoming brighter. This will soon stop ; the mass will grow dark and gradually cool down. As soon as it reaches the ordinary temperature, break the tube and put the contents in a mortar. Does the mass look like the mixture of sulphur and iron with which you started ? An examination with the microscope, the magnet, and bisulphide of carbon will prove that, while there may be a little iron left and possibly a little sulphur, most of the bluish-black mass is neither iron nor sulphur, but a new substance with properties quite different from those of iron and sulphur. Treat a little of the substance with dilute sulphuric acid. Also treat a little of the mixture of iron and sulphur with dilute sulphuric acid. What difference do you observe between the two cases ? Notice the odor.

What has Become of the Iron and the Sulphur ?—In the last experiment a new substance was formed by the action of sulphur upon iron. Neither substance has been destroyed, but both have combined in a much more intimate way than when they were simply mixed together. This kind of combination which causes the characteristic properties of the combining substances to disappear is called chemical combination. Nothing is lost in the act, as can be shown by weighing the substances before and after action.

Mechanical Mixtures and Chemical Compounds.—*In a mixture the substances are unchanged. They exist side by side. In a chemical compound the substances which are in combination are completely changed. They are so intimately combined that they cannot be recognized by ordinary means.*

Compounds and Elements.—Most of the substances found in nature are made up of several others. Wood, for example, is very complex, containing a large number of distinct substances intimately mixed together. Some of

these can be got out separately, but it is impossible to get them all out separately with the means at present at our command. Most of the rocks met with, and the different kinds of earth, as clay, sand, etc., are also quite complex, and it is in most cases difficult to get out the substances contained in them. By proper methods, however, it is possible to decompose the complex substances found in nature so as to get simpler ones, and these again can usually be decomposed into still simpler ones which cannot be decomposed by any means known to us. Substances which we cannot decompose into simpler ones are called *elements*. Now, although there are thousands of different kinds of substances met with in nature, these are really made up of a comparatively small number of simple substances or elements. The number of elements thus far discovered is between seventy and eighty, but the larger number of these are rare, and we might have an excellent knowledge of the essentials of chemistry without any knowledge of these rare elements. We shall find that most things we have to deal with are really made up of about a dozen elements, and that most of the chemical changes that are taking place around us, and that we need to study in order to get an insight into the nature of chemical action, take place between this small number of elements.

An element is a substance that we cannot decompose into simpler substances.

A compound is a substance that can be decomposed into simpler ones. A compound contains two or more elements held together chemically.

Examples of Elements and Compounds.—As examples of elements may be mentioned iron, copper, tin, silver,

gold, sulphur, and lead. As stated in the last paragraph, they are called elements for the reason that they cannot be decomposed into simpler substances. Among familiar compounds may be mentioned water, common salt or sodium chloride, blue vitriol or copper sulphate, chlorate of potash or potassium chlorate, marble or calcium carbonate, sand or silicon dioxide. Each of these compounds consists of two or more elements held together in chemical combination. Water can be decomposed by various methods into two substances known as hydrogen and oxygen, and the sum of the weights of the hydrogen and oxygen obtained from a given weight of water is exactly equal to the weight of the water decomposed. Sodium chloride can be decomposed into the two elements sodium and chlorine, and the weight of the sodium added to the weight of the chlorine exactly equals the weight of the sodium chloride. On the other hand, the composition of an element cannot be changed without adding something to it.

Chemical Action.—Just as the earth attracts all bodies to it in some mysterious way which we call gravitation, just as the magnet attracts pieces of iron, so substances are drawn together chemically and, if they come in contact under the proper conditions, *chemical action* takes place. By this is meant that some change in composition is brought about; that the substances which are brought together disappear and new ones make their appearance. But the quantity of matter remains the same. The elements arrange themselves differently.

Three Kinds of Chemical Action.—The numerous cases of chemical action may be divided into three classes: (1) *combination;* (2) *decomposition;* and (3) *double decomposi-*

tion or *metathesis*. As an example of combination the case of the action of iron on sulphur may be taken. The two elements combine directly, forming a compound known as iron sulphide. The action may be represented thus:

$$\text{Iron} + \text{Sulphur} = \text{Iron Sulphide.}$$
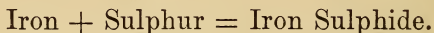
A good example of decomposition is that of the action of heat on the red oxide of mercury or mercuric oxide (see Experiment 2). When this substance is heated two things are obtained from it: an invisible gas, oxygen, which passes out of the vessel and can be detected by the fact that substances burn in it more readily th.n they do in air; and a silvery-looking liquid, which is quicksilver or mercury. The action in this case may be represented thus:

$$\text{Mercuric Oxide} = \text{Mercury} + \text{Oxygen.}$$

In double decomposition two or more substances act upon one another and give rise to the formation of two or more new ones. Thus when hydrochloric acid acts upon marble (see Experiment 3) two substances, calcium chloride and carbonic acid, are formed. This may be represented thus:

$$\text{Hydrochloric Acid} + \text{Calcium Carbonate (or marble)} =$$
$$\text{Calcium Chloride} + \text{Carbonic Acid.}$$
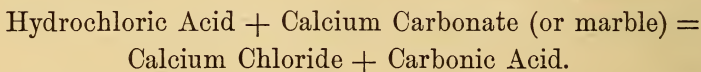
Most cases of chemical action which we have to deal with are of the third kind.

The Cause of Chemical Action.—It is evident from what we have already learned that there is some power which can hold substances together in a very intimate way, so intimate that we cannot recognize them by ordinary means. We do not know what causes sulphur and iron to

combine, but we know that they do combine. Similarly, we do not know what causes a stone thrown in the air to fall back again, but we know that it falls back. It is true we say that the cause of the falling of the stone is the *attraction of gravitation*, but this does not give us any information, for, if we ask what the attraction of gravitation is, we can only answer that it is that which causes all bodies to attract one another. So, too, we may say that the cause of the chemical union of substances is *chemical attraction*. But in so doing we are only giving a name to something about which we know nothing except the effects which it produces.

Importance of Chemical Action.—If this power, whatever it may be, should cease to operate, what would be the result ? As far as we can see all substances known to be *chemical compounds* would be decomposed into the elements of which they are composed, and there would be only about seventy or eighty different kinds of substances. All living things would cease to exist, and in their place we should have three invisible gases and something very much like charcoal. Mountains would crumble to pieces, and all water would disappear, giving two invisible gases. The processes of life in its many forms would be impossible. These considerations will suffice to show the great importance of the subject of chemistry, and how impossible it is without some knowledge of this subject to form any conception in regard to the most important phenomena of the universe.

Occurrence of the Elements.—As has already been stated (p. 10), not more than a dozen elements enter largely into the composition of the earth. It has been estimated that

the solid crust of the earth is made up approximately as
represented in this table:

Oxygen...................................... 47.29 per cent.
Silicon... 27.21   "   "
Aluminium.................................... 7.81   "   "
Iron.. 5.46   "   "
Calcium....................................... 3.77   "   "
Magnesium................................. .... 2.68   "   "
Sodium.. 2.36   "   "
Potassium........................... .... 2.40   "   "

While oxygen forms a large proportion of the solid crust
of the earth, it forms a still larger proportion (eight
ninths) of water, and about one fifth of the air.   Carbon
is the principal element entering into the structure of
living things, while hydrogen, oxygen, and nitrogen also
are essential constituents of animals and plants.   Nitrogen
forms about four fifths of the air.

The Names of the Elements.—The names of the ele-
ments are formed in many different ways.   The name
chlorine is derived from a Greek word meaning greenish
yellow, as this is the color of chlorine.   Bromine comes
from a Greek word meaning a stench, a prominent char-
acteristic of bromine being its bad odor.   Hydrogen is
formed from two Greek words, one of which means water
and the other to produce, signifying that it enters into the
composition of water.   Potassium is an element found in
potash, and sodium is found in soda.

The Symbols of the Elements.—It is convenient to use
abbreviations for the names of the elements and com-
pounds.   Thus, instead of oxygen we may write simply
O, for hydrogen H, for nitrogen N, etc.   Frequently the
first letter of the name of the element is used as the
symbol.   If the names of two or more elements begin with

the same letter, this letter is used, but some other letter of the name is added. Thus, B is the symbol of boron, Ba of barium, Bi of bismuth, etc. In some cases the symbols are derived from the Latin names of the elements. Thus, the symbol of iron is Fe, from *ferrum;* of copper, Cu, from *cuprum;* of mercury, Hg, from *hydrargyrum*, etc. The symbols of the more common elements will soon become familiar by use. It is not desirable to attempt to commit them to memory at this stage.

List of the Elements and their Symbols.—In the table here given the names of those elements which are most widely distributed, and which form by far the largest part of the earth, are printed in SMALL CAPITALS. The names of those which are very rare are printed in *italics.*

ALUMINIUM.......Al	HYDROGEN........H	*Ruthenium*.......Ru
Antimony ....Sb	Indium...........In	*Samarium*........Sm
Argon............A	Iodine............I	*Scandium*........ Sc
Arsenic..........As	Iridium..........Ir	*Selenium*.........Se
Barium ....Ba	IRON.............Fe	SILICON..........Si
Bismuth.........Bi	*Krypton*..........Kr	Silver...........Ag
Boron............B	*Lanthanum*.......La	SODIUM..........Na
Bromine........ Br	Lead............Pb	Strontium ....Sr
Cadmium ....Cd	Lithium..........Li	Sulphur..........S
Cæsium...........Cs	MAGNESIUM......Mg	*Tantalum* ....Ta
CALCIUM........Ca	Manganese.. ....Mn	*Tellurium* ....Te
CARBON.......... C	Mercury.........Hg	*Thallium*.........Tl
Cerium...........Ce	Molybdenum.....Mo	*Thorium*.........Th
CHLORINE Cl	*Neodymium* .....Nd	*Thulium*.........Tu
Chromium........Cr	*Neon.* ....Ne	Tin ....Sn
Cobalt...........Co	Nickel...........Ni	Titanium.........Ti
Columbium........Cb	NITROGEN........N	Tungsten.........W
Copper...........Cu	*Osmium* ....Os	Uranium.........U
Erbium...........Er	OXYGEN.... .....O	Vanadium........V
Fluorine .... F	Palladium.. .....Pd	*Xenon*............X
Gadolinum ......Gd	Phosphorus.......P	*Ytterbium*........Yb
Gallium..........Ga	Platinum........Pt	*Yttrium.* ....Y
Germanium ......Ge	POTASSIUM... ....K	Zinc. ....Zn
Glucinum.........Gl	*Praseodymium*....Pr	Zirconium ......Zr
Gold.............Au	*Rhodium*.........Rh	
Helium...........He	*Rubidium* ....Rb	

What We Shall Study.—In the course which you have begun you will study only the most common elements and their action upon one another. In this way you will be able to learn much about the chemistry of many interesting things, such as burning, the rusting of iron, the growth of plants and animals, the extraction of useful metals from their ores, the manufacture of illuminating-gas, of soap, etc., etc., and at the same time you will acquire a knowledge of the general principles of chemistry which will enable you to take a more intelligent view of the universe than you can without this knowledge.

CHAPTER II.

THE CHEMISTRY OF THE AIR.

The Air Causes Chemical Changes.—One of the most interesting, most common, and most important chemical changes with which we are familiar is that which is known as burning. No matter how we may begin the study of the chemistry of the things around us, we are at once brought face to face with the fact that the air takes part in chemical change.

EXPERIMENT 13.—In a small porcelain crucible arranged as shown in Fig. 3 put a small piece of lead. Heat by means of a laboratory burner, and notice the changes that take place. After the lead is melted stir the substance with a thick iron wire while heating. Continue to heat and stir until the substance is no longer liquid. What is its appearance now? Let it cool. Is it lead? What difference is there between the action in this case and in the case of melting ice and cooling the water down again? Which is chemical action and which physical action? Why?
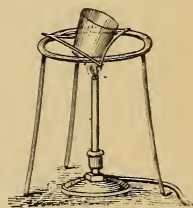
FIG. 3.

EXPERIMENT 14.—Heat a piece of zinc in the same way as you have just heated lead. What changes take place?

EXPERIMENT 15.—Heat a piece of tin in the same way. What changes take place?

What Caused the Changes?—By heating lead, zinc, and tin in the air, then, they are changed to powders which

do not melt. The question will suggest itself, does the heat alone cause these changes or has the air something to do with them? The air alone plainly does not cause the changes, for they do not take place until the substances are heated. To learn whether the air has anything to do with them we shall have to heat the substances in such a way as to keep the air from getting at them. This can be done by putting in the vessel something which melts and which will float on the melted metal. Such a substance is ordinary borax.

EXPERIMENT 16.—Repeat Experiments 13, 14, and 15, adding in each case enough borax to form a complete cover to the metal after both are melted. Do the metals melt? Are they changed to powders as in the previous experiments?

Many Similar Facts are Known.—The examples given above are only a few of a large number of similar ones known. Hence the statement that many metals when heated in the air undergo chemical change and are converted into powders which do not melt. The powders are formed by the action of the air on the heated metals, for if the air is kept away from the metals the changes do not take place.

The Metals Increase in Weight when Heated in the Air.—If you were to weigh the metals used in Experiments 13, 14, and 15 and then weigh the powders obtained, you would find that in each case the powder weighs more than the metal. This fact taken together with the others already learned shows that there is something in the air which at high temperatures combines with the metals tin, zinc, and lead.

Burning in the Air.—The phenomenon of burning takes place in the air, and the question suggests itself, has the

air anything to do with the burning? You know that if you shut up a stove completely the fire dies down, and unless the draught-door is opened the fire goes out. If you want the fire to burn more actively you open the draught-door, when air is drawn in and the burning is made to take place more rapidly. A fire burns better when air is blown into it with a bellows. A candle is put out when anything is brought down upon the flame in such a way as to keep out the air. When a smouldering fire is covered with ashes it goes out. All these facts, which are well known to every one, make it appear probable that the air has something to do with burning, but they do not show what. In order to learn this we shall have to experiment carefully, noticing everything that takes place.

EXPERIMENT 17.—Fix a short bit of candle on a large flat cork or a block of wood. Light the candle and place it with the block on the surface of water contained in a pail or some other appropriate vessel. Place over it a good-sized glass vessel, either a wide-mouthed bottle or a good-sized fruit-jar, as represented in Fig. 4, so that the candle and cork are in the glass vessel and the mouth of the vessel is beneath the

FIG. 4.

surface of the water. Hold it in this position for a few minutes and observe what takes place. Does the candle continue to burn ? Is all the air contained in the vessel used up when the candle goes out ? Try the experiment a second time, and when the flame is nearly extinguished raise the glass vessel so that air can get in. Does this make any difference ? What difference ? What do these experiments prove?
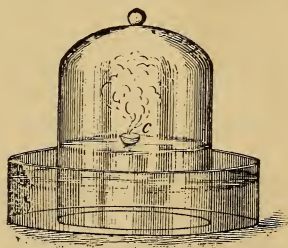
A Candle Will Not Burn in the Air that is Left.—If, after the candle has gone out, you place your hand or a

ground-glass plate over the mouth of the vessel and turn
it mouth upward, and then insert into it a lighted candle
on a wire, the candle will be extinguished. You see that
the air which is left in the vessel after a candle has burned
in it and gone out is not the same as ordinary air.

EXPERIMENT 18.—Try the experiment just mentioned. The
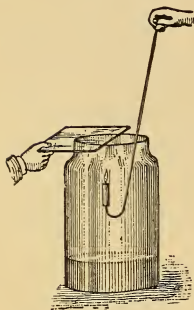candle on the wire should be arranged as shown in Fig. 5.

FIG. 5.

Does the Candle Increase in Weight?
—You know that in burning the candle
gradually disappears, and from this you
would be inclined to think that it is
destroyed. But if you were to collect
the smoke which is given off and weigh
it, you would find that it weighs more
than that part of the candle which has
burned up. So that instead of there being
a loss of matter there is apparently a gain.

EXPERIMENT 19.—On one pan of an appropriate balance place
a candle, and directly over it suspend a wide glass tube contain-
ing pieces of caustic soda, a substance which has the power to
absorb most of the smoke given off from the burning candle.
Place a similar glass tube with caustic soda on the other pan of
the balance and exactly balance the two pans. Now light the
candle, and in the course of a few minutes the pan with the
candle on it will sink, showing that it is heavier than the other.

**One Fifth of the Air is Used up when Anything Burns
in a Closed Vessel.**—By careful experiments which it
would be difficult to repeat here it has been shown that
only one fifth of the air is capable of keeping up the
process of burning, while the rest is an inactive substance
in which burning cannot take place. If, for example, you
could heat a piece of lead or zinc in a closed vessel for a

time, then let it cool and open the vessel under water, you
would find that water would
rush in and fill about one fifth
of the vessel, showing that
this much air had been used
up. If you should weigh the
metal before and after heat-
ing you would find that it had
increased in weight, and if
you should weigh the air used
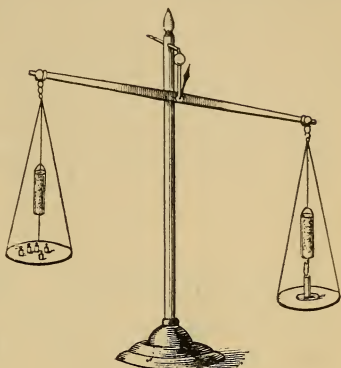up you would find that its
weight was exactly equal to the

FIG. 6.

increase of weight of the metal. A great many experi-
ments of this kind have been performed, and they have
shown that *when a substance burns it takes up something
from the air and increases in weight exactly as much as
the air loses.*

The Air Consists Mainly of Two Substances.—The air
then consists of two substances, only one of which can
keep up the process of burning. This one is known as
oxygen. The other, in which things cannot burn, is
known as *nitrogen.* Besides these the air always contains
smaller quantities of other substances, particularly *water
vapor, carbonic acid* (or carbon dioxide), *ammonia, argon,*
etc. We shall soon study these substances and learn
something about the part they play in the air. Oxygen
and nitrogen are called elements because no one has been
able to decompose them and get anything simpler from
them.

CHAPTER III.

OXYGEN

Occurrence of Oxygen.—Oxygen is the most widely distributed element, and it occurs also in very large quantity. It has been stated that it forms between forty and fifty per cent of the solid crust of the earth, eight ninths of water and one fifth of the air by bulk.

Preparation of Oxygen.—We have oxygen around us in great abundance in the air, but it is mixed with nitrogen, and it is difficult to separate the two so as to get the oxygen. The easiest way to get oxygen is by heating certain substances that contain it. One of the simplest examples of this kind is the oxide of mercury. When this is heated it gives mercury and oxygen. When mercury itself is heated in the air for some time to near its boiling point it is gradually changed to a red powder, just as lead and tin and zinc are changed to powders when heated in the air. This powder is a compound of mercury and oxygen. When the compound is heated to a high temperature it is decomposed into its elements, mercury and oxygen.

Collection of Oxygen.—The oxygen given off from the oxide of mercury is most conveniently collected by causing it to displace water. For this purpose the apparatus should be arranged as represented in Fig. 7. On heating

the oxide, the oxygen which is set free necessarily passes through the narrow tube and escapes beneath the mouth of the inverted glass vessel which is filled with water. The gas, being lighter than water and not very soluble in it, rises and the water is displaced. The oxide of mercury
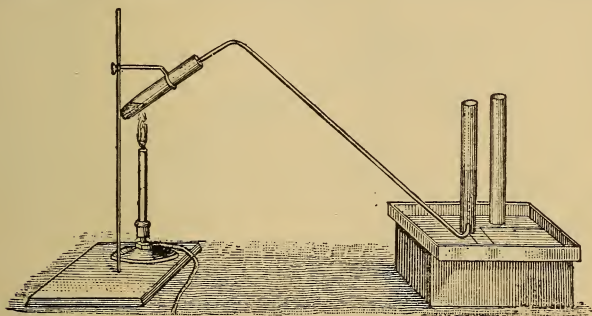

FIG. 7.

should be heated in a tube made of hard glass closed at one end.

Oxygen Made from Potassium Chlorate.—Another substance which readily gives up oxygen when heated is potassium chlorate or, as it is commonly called, chlorate of potash. This is manufactured in large quantities and is easily obtained. It contains the three elements potassium, chlorine, and oxygen. When heated it gives up the oxygen, and a compound of potassium and chlorine, known as potassium chloride, very much like common salt, is left behind.

EXPERIMENT 20.—Arrange an apparatus as shown in Fig. 8. *A* represents a retort of about 100 c.c. capacity. *B* is a piece of rubber tubing which is in turn connected with a piece of glass tubing bent upward at the end. This end is placed under the surface of the water in *C*. In *A* put 2 or 3 grams (about a sixteenth of an ounce) of potassium chlorate, and gently heat by means of the burner. Notice carefully what takes place. When gas comes off

freely bring the inverted cylinder *E* filled with water over the
end *D* of the tube, and let the bubbles of gas rise in the cylinder.
Examine the gas by placing a glass plate over the mouth of the
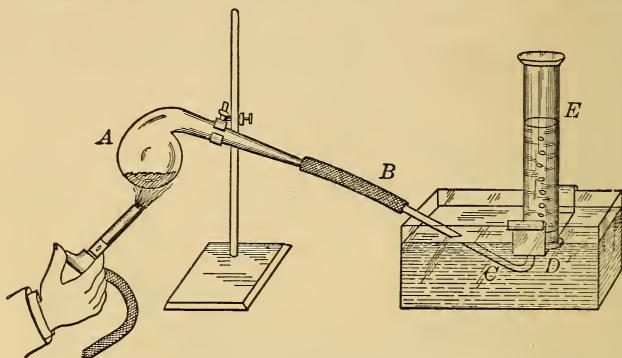vessel containing it and inverting it.   Insert into it a stick with

FIG. 8.

a spark on its end.   What takes place ?   Is the gas contained in
the vessel ordinary air ?

**Oxygen Made by Heating a Mixture of Potassium
Chlorate and Manganese Dioxide.**—The most convenient
way to make oxygen in the laboratory is to heat a mixture
of equal parts of potassium chlorate and manganese
dioxide or "black oxide of manganese."   This mixture
gives off oxygen readily when heated.   The potassium chlo-
rate alone is decomposed under these circumstances, the
manganese dioxide remaining unchanged.   It is not defi-
nitely known how the manganese dioxide helps the action.

EXPERIMENT 21.—Mix about 10 grams (or about a quarter of an
ounce) of potassium chlorate with an equal weight of *coarsely*
powdered manganese dioxide in a mortar.   Heat the mixture * in

* Black oxide of manganese is sometimes adulterated with other
substances, and when heated with potassium chlorate it may then
give rise to explosions.   It should be tested before using by mixing
a very small quantity with potassium chlorate and heating in a test-
tube.   If the decomposition takes place quietly the substance may
be used for the preparation of oxygen.

a glass retort arranged as shown in Fig. 8 and collect the gas by displacement of water in appropriate vessels—cylinders, bell-glasses bottles with wide mouths, etc.

Physical Properties of Oxygen.—Having thus learned how to get oxygen, you may proceed to study its properties. In the first place, the gas is invisible. The slight cloud that appears in the vessels when the gas is first collected is due to the presence of a very small quantity of a substance that is not oxygen. If the vessels are allowed to stand for a few minutes the cloud will disappear, and the vessels will look as if they were filled with air. The gas is tasteless and inodorous. [Inhale a little from one of the small bottles.] It is slightly heavier than the air. When subjected to an extremely high pressure and low temperature it is converted into a blue liquid. The properties of oxygen to which reference has thus far been made are its *physical properties*. These are its appearance, taste, smell, relative weight, and changes in its condition which still leave it in the elementary form or uncombined chemically.

Chemical Conduct of Oxygen.—In order to get an idea of the way in which oxygen acts upon some simple substances under ordinary circumstances a few experiments should be performed. We want to learn: What changes oxygen can effect in other substances; what conditions are necessary in order that it may act chemically; what products are formed, etc., etc.

The Action of Oxygen at the Ordinary Temperature.

EXPERIMENT 22.—Turn three of the bottles containing oxygen with the mouth upward, leaving them covered with glass plates. Into one introduce a little sulphur in a so-called deflagrating-spoon,—a small cup of iron or brass attached to a stout wire that

passes through a round metal plate, usually of tin (see Fig. 9).
In another put a little charcoal (carbon), and in a third a piece of
phosphorus * about the size of a pea. Let them stand quietly and
notice what changes, if any, take place.

What these Experiments Show.—These experiments
show that oxygen does not act upon sulphur and carbon
when brought in contact with them at the ordinary tem-
perature, and that the action upon phosphorus is slight.
We might perform experiments of this kind with a great
many substances, and we should reach the conclusion that
at the ordinary temperature oxygen does not readily act
upon substances. Indeed, as the air contains a consider-
able proportion of oxygen, it is clear that oxygen does not
readily act upon substances at ordinary temperatures or
action would constantly be taking place between the air
and many of the substances exposed to it.

Slow Action of Oxygen at the Ordinary Temperature.—
Upon some substances oxygen does act even at ordinary
temperature. Some metals, as iron, become covered with
a layer of rust when exposed to the air. This is due
partly, at least, to the action of the oxygen of the air.
Wood and other vegetable substances undergo slow decom-
position when exposed to the air, in consequence of the
action of the oxygen. Animal substances undergo decom-
position comparatively readily when exposed to the air.
The process of decay is partly due to the action of oxygen
at the ordinary temperature.

* Phosphorus should be handled with great care. It is kept
under water, usually in the form of sticks. If a small piece is
wanted, take out a stick with a pair of forceps, and put it under
water in an evaporating-dish. *While it is under the water* cut off a
piece of the size wanted. Take this out by means of a pair of
forceps, lay it for a moment on a piece of filter-paper, which will
absorb most of the water, then quickly put it in a spoon.

The Action of Oxygen in Animal Bodies.—The most important illustration of the action of oxygen at low temperatures is that which takes place in our bodies and the bodies of all animals. The food that we partake of undergoes many changes; some of the substances uniting with oxygen. Then, too, we take large quantities of oxygen into our lungs in *breathing*. This acts upon various substances that are presented to it in the lungs; it combines with them, forming other substances that can easily be got rid of. More will be said in regard to the breathing of animals and plants when the subject of carbon and its compounds with oxygen is taken up.

The Action of Oxygen upon Heated Substances.—Suppose that before putting them in the oxygen we heat the substances in Experiment 22, what will then take place?

EXPERIMENT 23.—In a deflagrating-spoon set fire to a little sulphur and let it burn *in the air*. Notice whether it burns with ease or with difficulty. Notice the odor of the fumes which are given off. Now set fire to another small portion and introduce it in a spoon into one of the vessels containing oxygen, as shown in Fig. 8. Does the sulphur burn more readily in the oxygen or in the air? Notice the odor of the fumes given off. Is it the same as that noticed when the burning takes place in the air?

EXPERIMENT 24. — Perform similar experiments with charcoal.

EXPERIMENT 25.—Burn a *small* piece of phosphorus in the air and in oxygen. In the latter case the light emitted from the burning phosphorus is so intense that it is painful to some eyes to look at it. After the burning is over let the vessel stand. Does it become clear?
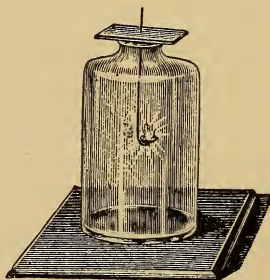

FIG. 9.

What Took Place in these Experiments?—In the first place, the substances were simply heated before they were

introduced into the oxygen. Nothing was added to them. It is clear, therefore, that while oxygen does not act upon these substances at the ordinary temperature, it does act upon them at higher temperatures. But what does the action consist in ? We can determine this only by a careful study of the substances before and after the action. We must know not only what substances are brought together, *but also what the weight of each is;* and we must know what substances are left behind, and *the exact weight of these.* By means of accurate experiments it has been shown repeatedly that the substances which burn in oxygen disappear as such, and that in each case a definite quantity of oxygen is also taken up. The result of the experiments can be stated thus: *The weight of the substance burned plus the weight of the oxygen taken up is exactly equal to the weight of the product formed.*

Burning is Combining with Oxygen.—From what we have learned we may conclude that when a substance burns in oxygen the act consists in the chemical combination of the two.

Burning in the Air.—To determine whether burning in the air is the same act as burning in oxygen it is necessary to burn the same things in air and in pure oxygen and see whether the products are the same. This has been done a great many times, and always with the same result. Whether a substance burns in the air or in pure oxygen the same product is formed, and nothing else. It is therefore certain that the act of burning in the air is due to the presence of oxygen. As we have already seen, there is another substance present in the air in large quantity,

and it is due to this fact that burning does not take place as readily in the air as in oxygen.

Combustion.—By the term combustion in its broadest sense is meant any chemical act that is accompanied by an evolution of light and heat. Ordinarily, however, it means the union of substances with oxygen as this union takes place in the air, with evolution of light and heat. Substances that have the power to unite with oxygen are said to be *combustible,* and substances that have not this power are said to be *incombustible.* Most of the elements combine with oxygen under proper conditions, and are therefore combustible. Most compounds formed by the union of oxygen with combustible substances are incombustible. They contain oxygen and they cannot directly combine with any more.

Some Substances that do not Burn in the Air Burn in Oxygen.—The best illustration of this fact is that of iron. This metal, as you know, does not burn in the air under ordinary circumstances. If it did, all our stoves, iron vessels, and iron buildings would burn up. In pure oxygen, however, iron burns readily.

EXPERIMENT 26.—Straighten a steel watch-spring * and fasten it in a piece of metal, such as is used for fixing a deflagrating-spoon in an upright position ; wind a little thread around the lower end, and dip it in melted sulphur. Set fire to this and insert it into a vessel containing oxygen. For a moment the sulphur will burn as in Experiment 23; but soon the steel will begin to burn brilliantly, and the burning will continue as long as there is oxygen left in the vessel. The phenomenon is of great beauty,

* Old watch-springs can generally be had of any watch maker or mender for the asking. A spring can be straightened by unrolling it, attaching a weight, and suspending the weight by the spring. The spring is then heated to redness from one end to the other by means of a Bunsen burner.

especially if observed in a dark room. The walls of the vessel become covered with a dark reddish-brown substance, some of which will also be found at the bottom in large pieces.—Instead of the watch-spring iron picture-wire may be used. It is only necessary to heat the end and dip it into powdered sulphur before putting it into the vessel containing the oxygen.

Kindling Temperature.—You have seen that substances do not usually combine with oxygen at ordinary temperatures, but that in order to effect the union the temperature must be raised. If this were not the case it is plain that every combustible substance in nature would burn up, for the air supplies a sufficient quantity of oxygen for this purpose. Some substances need to be heated to a high temperature before they will combine with oxygen; others require to be heated only slightly. Every combustible substance has its *kindling temperature*—that is, the temperature at which it will unite with oxygen. Below this temperature it will not unite with oxygen. Watch a stick of wood burning, and observe how, as we say, "the fire creeps" along it. The reason of the slow advance is simply this: only those parts of the stick which are nearest the burning part become heated to the kindling temperature. They take fire and heat the parts nearest them, and so on gradually throughout the length of the stick.

Heat a Result of Combustion.—We know that whenever a thing burns it gives out heat, and generally light. The heat is a result of the act of chemical combination, and the light is due to the heat. In general, *whenever chemical combination takes place heat is given off*. This is probably due to the rapid coming together of the particles of the substances that combine, just as a bullet is heated by being rapidly projected against a hard target that stops it.

Chemical Energy and Chemical Work.—Any substance that has the power to combine with others can do *chemical work;* it possesses *chemical energy.* Thus all combustible substances can do work. In combining with oxygen heat is given off, and this can be changed into motion. To go back to the example of the steam-engine, that was referred to in Chapter I, the cause of the motion is the burning of the fuel.

Products of Combustion.—The substances formed in combustion are in general known as *oxides.* The compound of zinc and oxygen is called *zinc oxide;* that of silver and oxygen, *silver oxide,* etc.

CHAPTER IV.

COMBINING WEIGHTS

Elements Combine in Definite Weight. — A certain weight of tin always combines with a definite weight of oxygen. If equal weights of sulphur and iron are mixed and caused to act chemically by the aid of heat, it will be found that some of the sulphur is left over in the uncombined state after the action is over. If we should take twice as much iron as sulphur, then, after the action, some iron would be left over. An extensive examination has shown conclusively that each chemical compound always contains the same elements in exactly the same proportions. The compound of sulphur and iron always contains exactly 36.41 per cent of sulphur and 63.59 per cent of iron. The compound of tin and oxygen always contains exactly 78.74 per cent of tin and 21.26 per cent of oxygen, and so on throughout the list of chemical elements.

The Law of Definite Proportions. — These facts were discovered by the united efforts of a large number of chemists continued through many years. They are of great importance. They are summed up in the general statement:

Chemical combination always takes place between definite weights of substances.

This is known as the *law of definite proportions.*

What a Natural Law is.—A natural law is simply a statement of what we have every reason to believe to be the truth. Every fact known to us in regard to chemical combination is in accordance with the law of definite proportions. It expresses what has been learned by a study of chemical facts. This law, as well as other natural laws, can never be proved to be absolutely true, for the reason that we cannot examine every case to which the law applies. But if, after examining a very large number of cases, we find that the law holds true in them, we may conclude that it is true of all cases. When we say that all bodies attract one another, do we know this to be absolutely true? Certainly not. But we do know that so far as those bodies are concerned which come under our observation the statement is true, and therefore we have reason to believe that it is true of all bodies.

Proportions by Weight in which the Elements Combine. —A careful study of the figures representing the composition of chemical compounds reveals a remarkable fact regarding the relative quantities of one and the same element which enter into combination with other elements. The proportions by weight in which some of the elements combine chemically are stated in the following table:

Sulphur 1; Oxygen 1.	Iron 7; Oxygen 2.	Iron 7; Sulphur 4.
Magnesium 3; Oxygen 2.	Tin 59; Oxygen 16.	Zinc 65; Oxygen 16.
Tin 59; Sulphur 16.	Zinc 65; Sulphur 32.	Sodium 23; Oxygen 8.
Sodium 23; Sulphur 16.	Potassium 39; Oxygen 8.	Potassium 39; Sulphur 16.

You see that for iron, tin, zinc, sodium, and potassium the same figures are used, whether you have the compounds of these elements with oxygen or with sulphur. Now, if we were to determine the composition of all compounds which contain zinc, we should find that the relative weight of zinc present could, in nearly all cases, be expressed by the number 65. Similarly the quantity of sodium in sodium compounds could be expressed by the number 23, and that of potassium in potassium compounds by 39.

Combining Weights of the Elements.—For every element a certain number can be selected, such that the proportions by weight in which this element enters into combination with others can be expressed by the number or by a simple multiple of it. These numbers are called the *combining weights*. It is not by any means an easy matter to determine which numbers are most convenient for all cases; and if the selection is to be determined solely by convenience, there may be differences of opinion as to what is most convenient. We shall see a little later that while the numbers primarily express the combining weights and nothing else, and are based solely upon determinations of the composition of chemical compounds, they have come to have a deeper meaning, and are now determined by methods that cannot easily be explained at this stage. The facts which it is important that you should understand now are:

(1) That chemical action takes place between definite weights of substances; and

(2) That the relative weights of the elements which enter into combination with one another can be expressed by numbers called the combining weights.

Symbols of Chemical Compounds.—You have learned that the chemist uses a kind of short-hand to express the names of the elements. Instead of the name oxygen he writes the symbol O, etc. Now these symbols stand not only for the names but also for the combining weights of the elements. Thus, O stands not only for the name oxygen but for 16 parts by weight; Fe stands for 56 parts by weight of iron, etc. To express a compound in the short-hand, the symbols of the elements contained in it are simply placed side by side. Thus, common salt or sodium chloride consists of the elements sodium and chlorine, which are combined in the proportion of their combining weights. The symbol of the compound is NaCl, which means a compound of the elements sodium and chlorine in the proportion 23 parts by weight of sodium and 35.5 of chlorine.

What is Meant by "Parts by Weight."—When we say that "O stands not only for the name oxygen but for 16 parts by weight" we have in mind an imaginary standard. What O really stands for is 16 times the weight of matter represented by H which stands for 1 part by weight of hydrogen. The reason why hydrogen is selected as the standard of comparison will be pointed out later.

How Chemists Express Chemical Reactions.—The symbols are of great convenience when it is desired to express what has taken place in a chemical reaction. Thus you have seen that when the compound mercury oxide, HgO, is heated, it is decomposed into mercury and oxygen, a fact which is clearly expressed by the equation

$$HgO = Hg + O,$$

which tells not only the fact that decomposition takes

place but the proportions by weight in which the substances take part. Thus, the compound, HgO, contains the elements in the proportion of 200 parts by weight of mercury to 16 of oxygen. When 216 parts by weight of this compound are decomposed 200 parts by weight of mercury and 16 of oxygen are obtained. As in chemical reactions matter is neither destroyed nor created, the same weight of matter must be represented on each side of the equation, or "the equation must balance."

A Chemical Problem.—Suppose you wish to know how much oxygen is contained in 50 grams of mercury oxide, how could you determine it? You know that in 216 parts by weight of the compound there are 16 parts by weight of oxygen; or, that in 216 grams of the compound there are 16 grams of oxygen. How many grams of oxygen are there in 50 grams of the compound? Plainly the answer is given by solving the expression

216 : 50 :: 16 : the number of grams of oxygen contained in 50 grams of the oxide.

Or $\frac{16}{216}$ of mercuric oxide being oxygen, how much oxygen is there is 50 grams of the oxide? Plainly $\frac{16}{216} \times 50 = 3\frac{19}{27}$ grams.

Law of Multiple Proportions.—Two elements frequently combine in more than one set of proportions. Thus, while ordinarily iron and sulphur combine in the proportion 56 of iron to 32 of sulphur, they also combine in the proportion 56 of iron to 64 of sulphur. Tin combines with oxygen in two proportions, forming two distinct compounds. In one 118 parts of tin are combined with 16 parts of oxygen; in the other 118 parts of tin are combined with 32 parts of oxygen. The elements potassium, chlo-

rine, and oxygen combine in several proportions as represented here:

Potassium	39	39	39	39
Chlorine	35.5	35.5	35.5	35.5
Oxygen	16	32	48	64

It will be observed that while in the compounds mentioned the quantities of oxygen and sulphur united with the same element or elements vary, these quantities are closely related to one another. In the case of iron and sulphur there is twice as much sulphur, relatively, in one compound as in the other. So, also, in the compounds of tin and oxygen there is twice as much oxygen combined with a given quantity of tin in one case as in the other. Finally, in the four compounds which are made up of potassium, chlorine, and oxygen the quantity of oxygen varies, being twice as great in the second compound as in the first, three times as great in the third, and four times as great in the fourth. These facts, and others of the same kind, are summed up in the *Law of Multiple Proportions*, which may be stated thus:

If two elements, A and B, combine in different proportions, the relative quantities of B which combine with any fixed quantity of A bear a simple ratio to one another.

The case of the compounds of potassium, chlorine, and oxygen does not come exactly under this law, as they do not consist of two elements. It will be observed, however, that these compounds illustrate the same principle. The relative weights of the potassium and chlorine do not change, while the weights of oxygen combined with fixed quantities of the other two elements bear a simple ratio to one another.

Symbols of Compounds of Elements Combined in More than One Proportion.—As has already been stated, when two elements combine in the simplest proportion the symbol of the compound is made by putting the symbols of the elements side by side, as in HgO, $NaCl$, etc., etc. If it is desired to represent compounds of the same elements combined in different proportions, use is made of small figures placed below the line, as in the symbols SO_2, CO_2, H_2SO_4, etc., etc. The meaning of the figures is this: In the compound SO_2 sulphur and oxygen are combined in the proportion of the combining weight (32) of sulphur and *twice* the combining weight (16) of oxygen, or 32 parts by weight of sulphur to 32 parts by weight of oxygen, which happens to be the same as 1 part by weight of one to 1 part by weight of the other. The symbol H_2SO_4 represents a compound made up of hydrogen, sulphur, and oxygen in the proportion *twice* the combining weight of hydrogen (1), the combining weight of sulphur (32), and *four times* the combining weight of oxygen (16); or 2 parts by weight hydrogen, 32 parts by weight sulphur, and 64 parts by weight oxygen, making all together 98 parts by weight of the compound.

PROBLEM.—How much sulphur is there in 60 grams of the compound H_2SO_4 (sulphuric acid) ? How much oxygen ? How much hydrogen ?

CHAPTER V.

NITROGEN

Occurrence of Nitrogen.—You have already learned that about four fifths of the bulk of the air is nitrogen. This element is also found in combination in a large number of substances in nature. It is found in the nitrates, as saltpetre or potassium nitrate, KNO_3, and Chili saltpetre or sodium nitrate, $NaNO_3$. It is also found in the form of ammonia, which is a compound of nitrogen and hydrogen of the formula NH_3. Ammonia occurs in small quantity in the air, and is formed under a variety of conditions, which will be referred to when the substance is considered. Nitrogen occurs, further, in most animal substances in chemical combination.

Preparation of Nitrogen.—The most convenient way to prepare nitrogen is to burn a piece of phosphorus in a bell-jar over water. The reasons why phosphorus is better for the purpose than most other substances are (1) because it burns, that is combines with oxygen, easily; and (2) because the compound which it forms with oxygen (the product of combustion) is a solid and dissolves in water.

EXPERIMENT 27.—Place a wide-mouthed jar over water in a larger vessel of water. In the middle of a flat cork about three inches in diameter fasten a small porcelain crucible, and float this on the water in the trough. Put into it a piece of phosphorus

about twice the size of a pea, and set fire to the phosphorus. Quickly place the jar over it on a support which will prevent the jar from sinking more than an inch or two in the water. At first some air will be driven out of the vessel on account of the expansion due to the heat. After the burning has stopped cover the mouth of the jar with a glass plate and turn it mouth upward. Try the effect of introducing successively several burning bodies into the nitrogen, as, for example, a candle, a piece of sulphur, phosphorus, etc.

Other Substances besides Phosphorus may be Used.— Anything that has the power to combine with oxygen may be used in the preparation of nitrogen from the air. Metallic copper is convenient, and is sometimes used. It is only necessary to pass air over heated copper, when the metal combines with oxygen, forming the solid copper oxide, CuO, leaving the nitrogen uncombined.

Properties of Nitrogen.—You have seen that nitrogen is a colorless, tasteless, inodorous gas. At very low temperature and under high pressure it is transformed into a liquid. It does not support combustion, nor does it burn. [Suppose nitrogen were combustible, how would this affect the composition of the atmosphere?] Nitrogen not only does not combine with oxygen readily, but it does not combine with any other element easily except at a very high temperature, and then with only a few. Just as it does not support combustion, so also it does not support breathing. An animal would die in it, not on account of any active poisonous properties possessed by it, but on account of a lack of oxygen. In the air it serves the useful purpose of diluting the oxygen. If the air consisted only of oxygen, all processes of combustion would certainly be much more active than they now are. What the effect on animals of the continued breathing of oxygen would be it is difficult

to say, as but few experiments on this subject have been made.

Nitrogen and Oxygen are Mixed together, not Chemically Combined in the Air.—It is not an easy matter to prove this statement satisfactorily, but the evidence is so strong that no chemist doubts it.

(1) If nitrogen and oxygen are mixed together, the mixture acts like air. When they are mixed there is nothing to show that chemical action takes place. You have seen that the combination of two substances gives rise to changes in temperature. When nitrogen and oxygen are mixed together there is no change in the temperature of the gases.

(2) Substances known to be chemical compounds do not vary in composition; that of the air does vary slightly.

(3) Air dissolves somewhat in water. If air which has been thus dissolved is pumped out and analyzed, it is found to have a composition different from that of ordinary air. Instead of containing 1 volume of oxygen to 4 volumes of nitrogen, it will contain 1 volume of oxygen to 1.87 volumes of nitrogen. The relative quantity of oxygen is much larger in air which has been dissolved in water than in ordinary air. This is due to the fact that oxygen dissolves more readily in water than nitrogen does. If the gases were in chemical combination the compound would probably dissolve without change of composition.

Liquid Air.—It has been stated that both oxygen and nitrogen can be converted into liquids by subjecting them to high pressure and low temperature. As air is a mixture of these two elements, it follows that it can be liquefied. By subjecting it to high pressure and then letting it

escape through a very small opening it is cooled to a low temperature. If this cold air is allowed to play upon the vessel containing the compressed air the latter is partly liquefied. Very efficient machines have been constructed by which air can be liquefied in any desired quantity. The problem of its practical application has not yet been worked out.

Oxygen Prepared from Liquid Air.—When liquid air is allowed to stand under the ordinary pressure of the atmosphere the nitrogen boils off with some of the oxygen, and after a time nearly pure liquid oxygen is left. This furnishes a method of obtaining oxygen from the air. (Liquid nitrogen boils at − 196° C. Liquid oxygen boils at − 181° C., or 13° higher.)

Argon.—When nitrogen obtained from the air as above described is carefully examined it is found to contain about 1 per cent of another gaseous substance that is so much like nitrogen that it escaped detection until a few years ago (1894). It is called *argon*, from a Greek word signifying idle. This name was given to it because it cannot be made to combine with any other element. What part it plays in the air, if any, is not known.

Summary.—The air consists of nitrogen and oxygen in the proportion of 4 volumes of the former to 1 volume of the latter. Oxygen supports combustion; nitrogen does not. Oxygen supports respiration; nitrogen does not. Oxygen and nitrogen are elements. They are not chemically combined in the air. Oxygen is made by heating certain substances which contain it, as, for example, mercury oxide and potassium chlorate. Nitrogen is made by burning phosphorus in a closed vessel containing air.

Elements combine in definite proportions by weight (law of definite proportions).

In each element a number may be selected by means of which the proportion by weight in which it enters into combination may be expressed (combining weights).

If an element combines with another in more than one proportion, the quantities which enter into combination with a fixed quantity of the second element bear a simple ratio to one another (law of multiple proportions).

CHAPTER VI.

WATER.

Occurrence of Water in Nature.—The wide distribution of water on the earth is familiar to every one. But water also occurs in forms and conditions which prevent it from being easily recognized. Thus, all living things contain a large proportion of water, which can be driven off by heat. If a piece of wood or a piece of meat is heated, water passes off.

EXPERIMENT 28.—In a dry tube heat gently a small piece of wood. What evidence do you obtain that water is given off? Do the same thing with a piece of fresh meat.

Large Proportion of Water in Animal and Vegetable Substances.—The proportion of water in animal and vegetable substances is very great. If the body of a man weighing 150 pounds were put into an oven and thoroughly dried there would be left only about 50 pounds of solid matter, all the rest being water. As all meat, vegetables, and foodstuffs in general contain a similar large proportion of water, it is evident that water is an important article of commerce. When you buy four pounds of beef you pay for about three pounds of water and one pound of solid matter.

Water of Crystallization.—Many chemical compounds when deposited from solutions in water often appear in regular forms called crystals. These frequently enclose water in chemical combination, and this water is necessary in order that the substance may exist in the form of crystals. Water thus held in combination is called water of crystallization.

EXPERIMENT 29.—Dissolve some ordinary alum in water (6–8 ounces alum to 200 c.c. water) by the aid of heat. Filter through a plaited filter and allow the filtered solution to cool. Crystals of alum will be deposited. Pour off the liquid above and place a few of the crystals on a piece of dry filter-paper. After the water is all absorbed from them and they appear dry, put them in a dry test-tube and heat gently. What evidence have you that water is contained in the crystals?

EXPERIMENT 30.—Heat a piece of gypsum, which is the natural substance from which "plaster of Paris" is made. Does it contain water of crystallization?

EXPERIMENT 31.—Heat gently a few small crystals of copper sulphate or "blue vitriol." In this case the loss of water is accompanied by a loss of color. After all the water is driven off, the powder left behind is white. On dissolving it in water, however, the solution will be seen to be blue; and if this solution is evaporated until the substance is deposited, it will appear in the form of blue crystals.

Efflorescent and Deliquescent Substances.—Some substances that contain water of crystallization give it up very easily when exposed to the air. Such substances are called *efflorescent*.

EXPERIMENT 32.—Select a few crystals of sodium sulphate or Glauber's salt which have not lost their lustre. Put them on a watch-glass, and let them lie exposed to the air for an hour or two. They soon lose their lustre, and become white and powdery on the surface. Try the same experiment with sodium carbonate or crystallized soda.

Some compounds if deprived of their water of crystallization will take it up again when allowed to lie in an atmosphere containing moisture. Substances that take up water from the air and dissolve in this water are called *deliquescent*. As the air always contains moisture, it is only necessary to expose such compounds to the air in order to notice the change. It is well shown by the compound calcium chloride, $CaCl_2$. This substance has a remarkable power of attracting water and holding it in combination.

EXPERIMENT 33.—Expose a few pieces of calcium chloride to the air. Its surface will soon give evidence of being moist, and after a time the substance will dissolve in the water which is absorbed.

Water is a Compound.—That water is a compound and not an element can be shown by passing an electric current through it. If the ends of the wires connected with a galvanic battery are put in water a short distance apart it will be noticed that bubbles of gas rise from each wire. As these gases cannot well come from the wires, the most probable supposition is that they are formed from the water.

EXPERIMENT 34.—To the ends of the copper wires connected with two cells of a Bunsen's or Grove's battery fasten small platinum plates, say 25 mm. (1 inch) long by 12 mm. (½ inch) wide. Insert these platinum ends into water contained in a glass vessel about 15 cm. (6 inches) wide and 7 to 8 cm. (3 inches) deep, taking care to keep them separated from each other. No action will take place, for the reason that water will not conduct electricity, and hence when the platinum ends are kept apart there is no current. By adding to the water about one tenth its own volume of strong sulphuric acid it acquires the power to conduct electricity. It will then be observed that bubbles rise from each of the platinum plates. In order to collect the gases the ap-

paratus may be arranged as shown in Fig. 10. *h* and *o* represent glass tubes which may conveniently be about 30 cm. (1 foot) long and 25 mm. (1 inch) internal diameter. They should be marked by means of a file, or by etching, so that equal divisions can be recognized. Tubes thus marked so that the divisions indicate cubic centimetres are most convenient, and are easily obtained of dealers in chemical apparatus. The tubes are first filled with the water containing about one tenth its volume of sulphuric acid, and then placed with the mouth under water in the vessel *A*. The platinum ends are now brought beneath the inverted tubes. The bubbles will rise in them and displace the water. Gradually the water will be completely forced out of one of the tubes, while the other is still half full of water. The substance which we have thus collected in each of the tubes is an invisible gas. After the first tube is full of gas, remove it by placing your thumb over

Fig. 10.

the mouth. Turn it mouth upward, and at once apply a lighted match to it. A flame will be noticed. *The gas burns.* Is it air? Is it oxygen? Is it nitrogen? In the mean time the second tube will have become filled with gas. Remove the tube in the same way, and insert a thin piece of wood with a spark on the end. Does this gas act like oxygen? The gas collected in the tube which first became filled is known as *hydrogen*, while the other is *oxygen*.
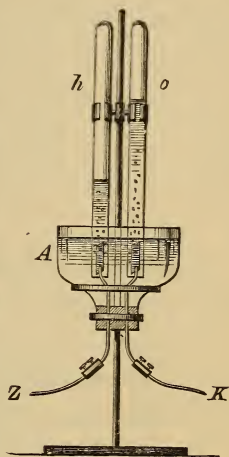
What the Experiment Shows.—The experiment just performed shows that when an electric current is passed through water hydrogen and oxygen are obtained, and also that there is obtained twice as much hydrogen by bulk as oxygen. Whether these are the only elements contained in water can only be shown by further experiments. But it will be necessary first to learn something about hydrogen.

CHAPTER VII.

HYDROGEN.

Occurrence of Hydrogen.—Hydrogen is found in nature very widely distributed, and in large quantity. It forms one ninth the weight of water, and is contained in all the principal substances that enter into the composition of plants and animals.

Preparation of Hydrogen.—It can be obtained

(*a*) By decomposition of water by means of the electric current;

(*b*) By decomposition of water by means of certain metals;

(*c*) By the action of substances known as acids on metals.

The first method has already been illustrated in Experiment 34.

Experiment 35.—Throw a small piece of sodium * on water. Cover the vessel with a piece of cardboard. While it is floating on the surface apply a lighted match to it. What takes place?

* The metals sodium and potassium are kept under kerosene oil. When a small piece is wanted, take out one of the larger pieces from the bottle, roughly wipe off the oil with filter-paper, and cut off a piece the size needed. It is not advisable to use a piece larger than a small pea. *Dry your fingers before handling these metals.*

The flame is due to burning hydrogen, the flame being colored yellow by the presence of sodium, some of which also burns.

EXPERIMENT 36.—Certain metals that do not decompose water at ordinary temperatures, or that decompose it slowly, decompose it easily at elevated temperatures. This is true of iron. If steam is passed through a tube containing pieces of iron turnings or fine bright iron wire heated to redness, the water is decomposed, the oxygen is retained by the iron in chemical combination, while the hydrogen is liberated. In this experiment a porcelain tube with an internal diameter of from 20 to 25 mm. (about an inch) and a gas-furnace are desirable, though a hard glass tube and a charcoal-furnace will answer. The arrangement of the apparatus is shown in Fig. 11.
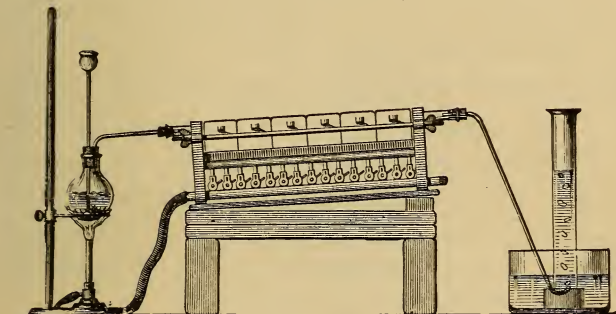
FIG. 11.

Water-gas.—Many other substances have the power to decompose water and set hydrogen free. The fact that a combustible gas can be obtained from water has led to many attempts to manufacture gas for heating and illuminating purposes from water. There is, however, no cheap substance which has the power to decompose water at ordinary temperatures. Heat must be used, and it is generally the case that the quantity of heat required to effect the decomposition is greater than that which would be obtained by burning the hydrogen formed. The

so-called "water-gas" now so extensively manufactured in the United States both for illuminating and heating is made by the action of highly heated hard coal on steam. The essential part of the chemical reaction is represented by the equation

$$C + H_2O = CO + 2H.$$
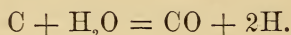
Carbon (or coal) acting upon the water (H_2O) combines with the oxygen, forming the compound carbon monoxide, CO, and leaving the hydrogen uncombined. Both products are gases, and both burn; and when this mixture is enriched by some of the oils obtained from petroleum it burns well and gives a good light.

The Common Acids.—Hydrogen is most conveniently made in the laboratory by treating a metal with an acid. As will be seen later, acids are substances that contain hydrogen, and that give up this hydrogen very easily. Among the common acids found in every laboratory are *hydrochloric acid*, *sulphuric acid*, and *nitric acid*. These compounds will be treated of farther on.

Hydrogen is Generally Given off when a Metallic Element Acts upon an Acid.—This is shown as follows:

EXPERIMENT. 37.—*Always be cautious in working with hydrogen. The danger consists in the fact that a mixture of hydrogen and oxygen or of hydrogen and air is extremely explosive. It requires a spark or a flame to explode it. Always let the gas escape for a time, and collect a test-tube full by displacement of water and then light it to see if it will burn quietly, before applying a flame to the gas issuing from the generating vessel.*—In a cylinder or test-tube put some small pieces of *granulated zinc*, and pour upon it enough ordinary hydrochloric acid to cover it. What do you notice? After the action has continued for a minute or two apply a lighted match to the mouth of the vessel. What takes place? Try the same experiment with sulphuric acid

diluted with six times its volume of water.* What is the result ? The gas given off is hydrogen. For the purpose of collecting it the operation is best performed in a bottle with two necks called a Woulff's flask (see Fig. 12), or in a wide-mouthed bottle in which is fitted a cork with two holes (see Fig 13). Through one of the holes passes a funnel-tube, and through the other a glass tube
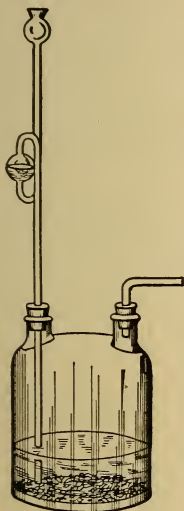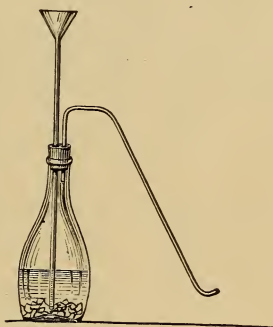
FIG. 12.   FIG. 13.

bent in a convenient form. Put a small handful of granulated zinc into the bottle and pour upon it enough of a *cooled* mixture of sulphuric acid and water (1 volume concentrated acid to 6 volumes of water) to cover it. Usually a brisk evolution of gas will take place at once. *Wait two or three minutes*, and then collect some of the gas by displacement of water. Should the action become slow add a little more of the dilute acid. It will be well to fill several cylinders and bottles with the gas.

* If it is desired to dilute ordinary concentrated sulphuric acid with water, the acid should be poured slowly into the water while the mixture is constantly stirred. If the water is poured into the acid, the heat evolved at the places where the two come in contact may be so great as to convert the water into steam and cause the strong acid to spatter.

Physical Properties of Hydrogen.—Hydrogen is a color-less, inodorous, tasteless gas. Made by the action of zinc on acids, it has a slightly disagreeable odor. This is due to the presence of small quantities of impurities. If these are removed the odor disappears.

EXPERIMENT 38.—Pass some of the gas through a solution of *potassium permanganate ;* collect some of it, and notice whether it has an odor. The apparatus should be arranged as shown in Fig. 14. The solution of potassium permanganate is, of course, contained in the small cylinder, *A*, and the tubes so arranged that the gas bubbles through it.

The gas is not poisonous, and may therefore be inhaled with impunity. We could not, however, live in an atmos-
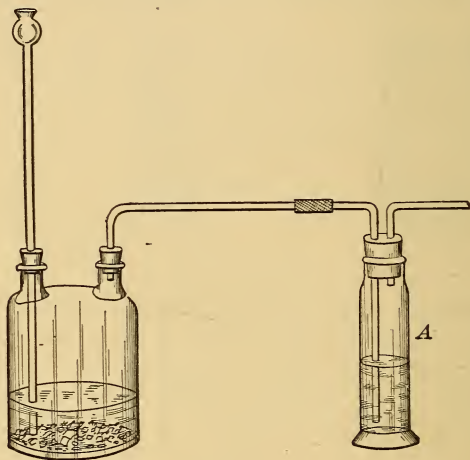
FIG. 14.

phere of hydrogen, as we must have oxygen. *It is the lightest substance known*, being fourteen and a half times lighter than air and sixteen times lighter than oxygen.

EXPERIMENT 39.—Place a vessel containing hydrogen with the mouth upward and uncovered. In a short time examine the gas and see whether it is hydrogen.

EXPERIMENT 40.—Gradually bring a vessel containing hydro-
gen with its mouth upward below
an inverted vessel containing
air, in the way shown in Fig. 15.
The air will be displaced. On
examination, the inverted vessel
will be found to contain hydro-
gen, while the one with the mouth
upward will contain none. The
gas is thus poured upward.
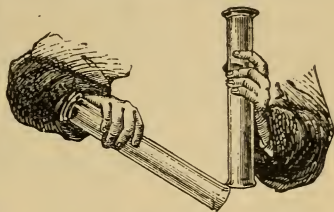
FIG. 15.

EXPERIMENT 41.—Soap-bubbles filled with hydrogen rise in the
air. The experiment is best performed by connecting an ordi-
nary clay pipe by means of a piece of rubber tubing with the
exit-tube of a gasometer filled with hydrogen. Small balloons of
collodion are also made for showing the lightness of hydrogen.
Large balloons are always filled with hydrogen or some other
light gas. Some kinds of illuminating-gas are rich in hydrogen,
and may therefore be used for the purpose.

Weight of Hydrogen Compared with that of Oxygen.—
A litre of hydrogen at 0° C. and under the pressure of the
atmosphere weighs 0.08995 gram. A litre of oxygen under
the same conditions weighs 1.429 grams. These figures
are to each other as 1 to 16. But the figures 1 and 16 are
the combining weights of hydrogen and oxygen; that is
to say, they are the figures best adapted to expressing the
relative weights of these elements that enter into combina-
tion. A similar connection exists between the relative
weights of equal volumes of some other elementary gases
and their combining weights, as will be seen later.

**All Combining Weights are Referred to that of Hy-
drogen.—**The figures called the combining weights express
the relations between the weights of the different elements
which enter into combination. When we say that the
combining weight of hydrogen is 1 and that of oxygen is
16, we mean that the weight of oxygen which generally

enters into combination is sixteen times as great as the weight of hydrogen which enters into combination. The figures 2 and 32 would express this relation just as well; so would $6\frac{1}{4}$ and 100; but the simplest figures that can be used are 1 for hydrogen and 16 for oxygen. Having adopted these, all other combining weights are referred to these.

Hydrogen a Liquid.—At a very low temperature and high pressure hydrogen becomes liquid. This liquid boils at $-252°$ C.

Chemical Properties of Hydrogen. — Under ordinary circumstances hydrogen is not a particularly active element. It does not unite with oxygen at ordinary temperatures, but, like wood and most other combustible substances, needs to be heated up to its kindling temperature before it will burn. You have seen that it burns if a lighted match is applied to it. The flame is colorless or slightly blue. As burned under ordinary circumstances the flame is colored, in consequence of the presence of foreign substances; but that it is colorless when the gas is

Fig. 16.

burned alone can be shown by burning it from a platinum tube, which is itself not acted upon by the heat.

EXPERIMENT 42.—If there is no small platinum tube available, roll up a small piece of platinum-foil and melt it into the end of a glass tube, as shown in Fig. 16. Connect the burner thus made with a bottle or gasometer containing hydrogen, and after the gas has been allowed to issue from it for a moment * set fire to it. In a short time it will be seen that the flame is practically color-less and gives no light. That it is hot is shown by holding a piece of platinum wire or a piece of some other metal in it.

* Be cautious. See Experiment 37.

The Burning of Hydrogen.—Hydrogen burns. You have already learned that burning consists in combining with oxygen. On the other hand, substances that burn in the air are extinguished when put in a vessel containing hydrogen. This is the same as saying that a body which is combining with oxygen does not continue to combine with oxygen when it is put in an atmosphere of hydrogen, and does not combine with hydrogen. This is expressed by saying that hydrogen does not support combustion.

FIG. 17.

EXPERIMENT 43.—Hold a wide-mouthed bottle or cylinder filled with hydrogen with the mouth downward. Insert into the vessel a lighted taper held on a bent wire, as shown in Fig. 17. The gas takes fire at the mouth of the vessel, but the taper is extinguished. On withdrawing the taper and holding the wick for a moment in the burning hydrogen, it will take fire if there is a spark in it, but on putting it back in the hydrogen it will again be extinguished. Other burning substances should be tried in the same way.
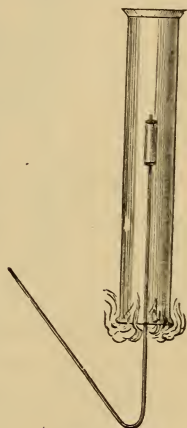
CHAPTER VIII.

WATER (*Continued*).

Composition of Water.—In Chapter VI you learned that hydrogen and oxygen are both set free when an electric current is passed through water containing a little sulphuric acid. It remains to be seen whether these are the only elements contained in water. If water consists only of hydrogen and oxygen, then when these elements combine water should be formed. But hydrogen combines with oxygen when it burns. Is water formed when hydrogen burns?

EXPERIMENT 44.—Pass hydrogen from a generating-flask or a gasometer through a tube containing some substance that will absorb moisture, for all gases collected over water are charged with moisture. You have seen in Experiment 33 that calcium chloride has the power to absorb moisture. It is extensively used in the laboratory for the purpose of drying gases, and it may be used in the present experiment. It should be in small pieces about the size of a pea, not powdered. After passing the hydrogen through the calcium chloride, pass it through a tube ending in a narrow opening and set fire to it. (Take the precaution mentioned in Experiment 37, page 50.) If now a *dry* vessel is held over the flame, drops of water will condense on its surface and run down. A convenient arrangement of the apparatus is shown in Fig 18. *A* is the calcium chloride tube. Before lighting the jet hold a glass plate in the escaping gas, and see whether water is deposited on it. Light the jet *before* putting it under the bell-jar ; otherwise, if hydrogen is allowed to escape into the ves-

sel it will contain a mixture of air and hydrogen, and this mixture, as has been stated, is explosive.
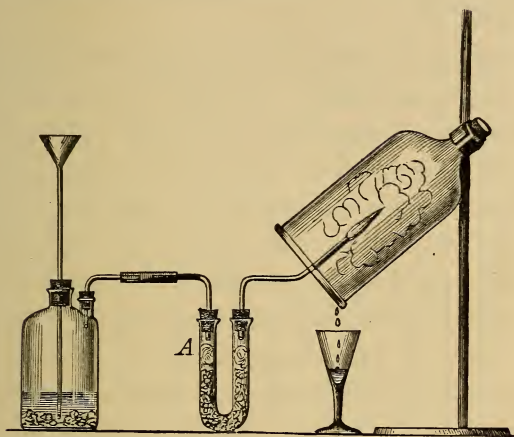
FIG. 18.

Hydrogen and Oxygen do not Combine at the Ordinary Temperature.—If they did, hydrogen would take fire the moment it comes in contact with the air. If we mix the gases together and allow the mixture to stand unmolested, it remains unchanged. If, however, we should bring a spark or a flame in contact with the mixture a violent explosion would occur, and a careful examination would show that the explosion is caused by the combination of the two gases. The combination causes heat. The heat causes the gases to expand greatly and suddenly, and the noise is caused by this sudden expansion. The expansion is followed by a contraction.

EXPERIMENT 45.—Mix hydrogen and oxygen in the proportion of about 2 volumes of hydrogen to 1 volume of oxygen in a gasometer or large bottle. Fill soap-bubbles, made as directed in Experiment 41, with this mixture and allow them to rise in the air. As each one rises bring a lighted taper in contact with it,

when a sharp explosion will occur.   Great care must be taken to keep all flames away from the neighborhood of the vessel containing the mixture.

Measuring the Volumes of Hydrogen and Oxygen that Combine to Form Water.—The last experiment simply showed that when a flame comes in contact with a mixture of hydrogen and oxygen an explosion occurs.   To show what else takes place the experiment must be performed in a closed vessel.   This experiment has been performed many times.   As it would be difficult for you to repeat it you will have to be satisfied with a description of the apparatus used and a statement of the result obtained. A tube is used which is marked on the outside so that the volume of gases contained in it can be seen.   This tube has two small platinum wires passed through it at the

closed end, nearly meeting inside and ending in loops outside, as shown in Fig. 19.   It is called a *eudiometer*.   It is filled with mercury and inverted in a trough containing mercury.   A quantity of pure hydrogen is now passed up into the tube and its volume accurately measured.   Then just half this volume of oxygen is introduced, and after the mixture has stood for a few minutes, so that the gases can become thoroughly mixed, an electric spark is passed between the wires inside the tube by connecting the loops with the poles of a small Ruhmkorff coil or with a Leyden jar.   The explosion takes place noiselessly and with very little danger.   If the interior of the tube was dry

FIG. 19.   before the explosion, it will be seen to be moist afterwards.   The liquid water which is formed occupies

almost no space as compared with the space occupied by the two gases before combination. Now, if the experiment is performed with the two gases in different proportions, it will be found that only when they are mixed in the proportion of 2 volumes of hydrogen to 1 volume of oxygen do they completely disappear when exploded. If there is a larger proportion of hydrogen present, the excess is left over. If there is a larger proportion of oxygen present, the excess of oxygen is left over. Thus it is shown that when hydrogen and oxygen combine to form water, they do so in the proportion of 2 volumes of hydrogen to 1 volume of oxygen.

Formation of Water by Passing Hydrogen over Heated Oxides.—Water can be formed by passing hydrogen over a compound containing oxygen and heating. A convenient substance for the purpose is the compound of copper and oxygen known as copper oxide or black oxide of copper. It contains its elements in the proportion represented by the formula CuO. At ordinary temperature hydrogen does not act upon this substance. At a high temperature the hydrogen combines with the oxygen, forming water, and the copper is left behind as such. The reaction is represented thus:

$$CuO + 2H = H_2O + Cu.$$
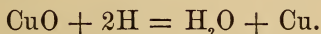
EXPERIMENT 46.—Arrange an apparatus as shown in Fig. 20. *A* is a Woulff's flask for generating hydrogen. To remove impurities the gas is passed through a solution of potassium permanganate contained in the wash-cylinder *B*. The U tube *C* contains granulated calcium chloride, and the cylinder *D* contains concentrated sulphuric acid, both of them serving to remove moisture from the glass. The pure dry hydrogen is now passed through the hard glass tube *E*, which contains a layer of copper

oxide. *After the apparatus is filled with hydrogen* the burner under *E* is lighted, and the copper oxide heated to low redness.
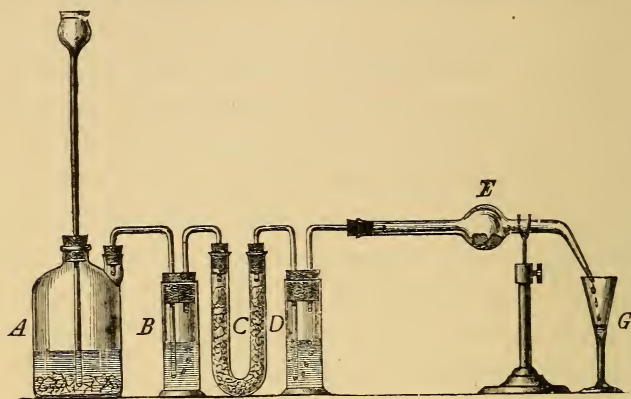
FIG. 20.

Soon moisture will be seen in the end of the tube and drops of water will collect in the vessel *G*.

How this Experiment Shows the Composition of Water. —The copper oxide loses its oxygen and of course loses weight. If, therefore, you should weigh the copper oxide before the experiment, and afterward the copper, and should also collect and weigh the water formed, you could from the figures obtained calculate the relative weight of oxygen contained in water, thus:

Let x = weight of tube + copper oxide before the experiment;
y = weight of tube + copper after the experiment.
Then $x - y$ = weight of oxygen taken from the copper oxide.

The water formed can be collected in a small tube containing calcium chloride.

Let a = weight of calcium chloride tube before;
b = weight of calcium chloride tube after.
Then $b - a$ = weight of water formed.

If the experiment is carefully performed, it will be found that $\dfrac{x-y}{b-a}$ is very nearly equal to $\frac{8}{9}$, which means that by weight oxygen forms eight ninths of water.

Oxidation and Reduction.—Any substance which like hydrogen has the power to abstract oxygen from compounds containing it is called a *reducing agent*. The process of abstracting oxygen from a compound is called *reduction*. *Reduction* and *oxidation* are opposite processes.

Applications of the Heat Evolved by the Combination of Hydrogen and Oxygen.—The heat evolved when hydrogen combines with oxygen is very great, and it is utilized for various purposes. To burn hydrogen in the air is, as we have seen, a simple matter, but to burn it in oxygen requires a special apparatus to prevent the mixing of the gases before they reach the end of the tube where the combustion takes place. The *oxyhydrogen blowpipe* answers this purpose. It is a tube with a smaller tube passing through it, as shown in Fig. 21.
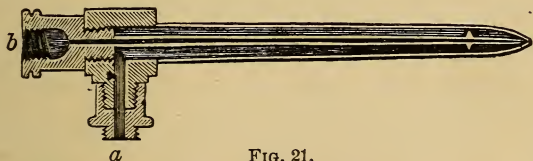
Fig. 21.

The hydrogen is admitted through a, and the oxygen through b. It will be seen that they come together only at the end of the tube. The hydrogen is first passed through and lighted; then the oxygen is passed through slowly, the pressure being increased until the flame appears thin and straight. It gives very little light, but it is intensely hot.

EXPERIMENT 47.—Hold in the flame of the oxyhydrogen blow-pipe successively a piece of iron wire, a piece of a steel watch-spring, a piece of copper wire, a piece of zinc, a piece of platinum wire.

The Oxyhydrogen Blowpipe Used in Working Platinum.—The metal platinum is used for many purposes, particularly for making chemical apparatus. The vessels are made from molten platinum, and the metal is melted by means of the oxyhydrogen blowpipe.

The Lime-light or Drummond Light.—When the flame of the oxyhydrogen blowpipe is made to strike against some substance which it cannot melt nor burn up, the substance becomes heated so high that it gives off intense light. The substance commonly used is quicklime. Hence the light is sometimes called the lime-light. It is also known as the Drummond light or calcium light.

EXPERIMENT 48.—Cut a piece of lime of convenient size and shape, say an inch long by three quarters of an inch wide and the same thickness. Fix it in position so that the flame of the oxy-hydrogen blowpipe will strike upon it. The light is very bright, but by no means as intense as the electric light.

Properties of Water.—Though, as we know, water is widely distributed over the earth, it is never found perfectly pure. All natural waters contain foreign substances in solution. These substances are taken up from the air or from the earth. Pure water is tasteless and inodorous. In thin layers it is colorless, but in thick layers it is blue. This has been shown in the laboratory by filling a long tube with distilled water. When looked through it appears blue. The beautiful blue color of some mountain lakes is the natural color of pure water.

On cooling water contracts until it reaches the tempera-

ture of 4° C. At this point it has its maximum density. When cooled below 4° it expands, and the specific gravity of ice is somewhat less than that of water. Hence ice floats on water.

Natural Waters.—The purest water found in nature is rain-water, particularly that which falls after it has rained for some time. That which first falls always contains impurities from the air. As soon as the rain-water comes in contact with the earth and begins its course toward the sea it begins to take up various substances, according to the character of the soil with which it comes in contact. Mountain streams which flow over rocky beds, particularly beds of sandstone, which is very insoluble in water, contain exceptionally pure water. Streams which flow over limestone dissolve some of the stone, and the water becomes "hard." The many varieties of mineral springs have their origin in the presence in the earth of certain substances which are soluble in water. Common salt occurs in large quantities in different parts of the earth. As it is easily soluble in water, many streams contain it; and as all the streams find their way into the ocean, you see one reason why the water of the ocean is salt.

Effervescent Waters are such as contain some gas, usually carbonic-acid gas, in solution and give up a part of it when placed in open vessels.

Chalybeate Waters contain some compound of iron.

Sulphur-water contains a compound of hydrogen and sulphur, called hydrogen sulphide or sulphuretted hydrogen (which see).

Impure Waters.—As streams approach the habitations of man they are likely to become contaminated. The

drainage (called sewage) from the neighborhood of human dwellings is very apt to find its way into a near stream. This condition of things is most strikingly illustrated by the case of a large town situated on the banks of a river. It often happens that the water of the river is used for drinking purposes, and it also happens that the water is contaminated by sewage. Water when once contaminated by sewage tends to become pure again by contact with the air in consequence partly of the action of the oxygen. Hence river-water may become fit for use after having been impure. If it is to be used for drinking purposes, however, it is not well to rely too much upon this process of purification.

Wells should not be dug too near dwellings and farm-houses, as the sewage may find its way into them beneath the surface of the earth. This is a frequent source of danger, as some diseases are communicated from one person to another by means of contaminated drinking-water.

Distillation.—Water can be purified by means of distillation. This consists in boiling the water, and then condensing the vapor by passing it through a tube kept cool by surrounding it with cold water. By means of distillation most substances in solution in water can be got rid of. Volatile substances, however, will of course pass over with the water vapor. Aboard ship salt water is distilled and thus made fit for drinking. In chemical laboratories ordinary water is distilled in order to purify it for fine work with chemical substances. A simple apparatus to illustrate the process of distillation is that shown in Fig. 22.

The water to be distilled is placed in the flask *A*. The flask is connected by means of a bent glass tube *B* with the long tube *C*. This in turn is surrounded by the larger tube or jacket *D*. The side tube *E* is connected with a faucet by means of the rubber tube *G*. The water is allowed to flow slowly into the jacket and out at *F*, whence it passes through the rubber tube *H* to the sink. When the water in *A* is boiled, the vapor passes into the
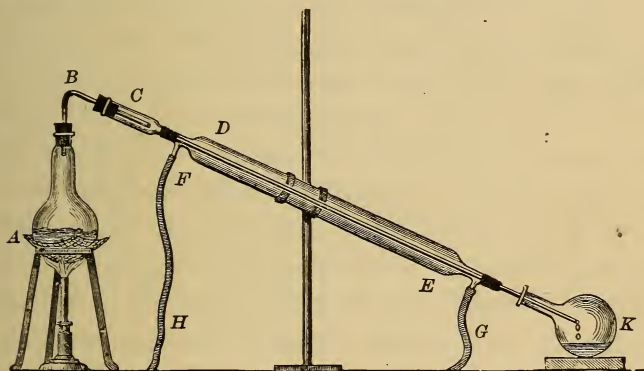
FIG. 22.

tube *C*. Here it is cooled down, and takes the form of liquid, which runs down and collects in the flask *K* called the receiver. The apparatus therefore consists of three parts: the *distilling-flask*, the *condenser*, and the *receiver*.

EXPERIMENT 49.—Dissolve some copper sulphate, or some other colored substance, in a litre of water, and distil the water.

Water as a Solvent.—It is known that many solids, liquids, and gases when brought into water disappear and form colorless liquids that look like water. Some give colored liquids of the same color as the dissolved substance, and others give liquids that have colors quite different from the dissolved substances. On the other

hand there are many substances that do not dissolve in
water. If a very small quantity of substance is dissolved
in a large quantity of water, and the solution thoroughly
stirred, the dissolved substance is uniformly distributed
throughout the liquid and remains so. That the dissolved
substance is everywhere present in the solution can be
shown, further, by the aid of certain dye-stuffs, as, for
example, magenta. A drop of a concentrated solution of
this substance brought into many gallons of water imparts
a distinct color to all parts of the liquid. An experiment
of this kind gives some idea of the extent to which the
subdivision of matter can be carried. For it is evident
that in each drop of the dilute solution some of the color-
ing matter must be contained, though the quantity must
be extremely small. While there seems to be no limit to
the extent to which a solution can be diluted, and still
retain the dissolved substance uniformly distributed
through its mass, there is a limit to the amount of every
substance that can be brought into solution, and this
varies with the temperature, and, in the case of gases, with
the pressure. Some substances are easily soluble; others
are difficultly soluble. When the solutions are boiled the
water passes off and leaves the dissolved substance behind,
if it is a non-volatile solid.

Solutions and Chemical Compounds.—Solutions, in gen-
eral, seem to differ from true chemical compounds in
some important particulars, and also from mechanical
mixtures. Definiteness of composition is a common char-
acteristic of chemical compounds, but solutions have no
definite composition. Any quantity of a substance, from
the minutest particle to a certain fixed quantity for any

given temperature, can be dissolved, and the solution formed is in each case uniform and appears to be a perfect solution.

Solution as an Aid to Chemical Action.—When it is desired to secure the chemical action of one solid substance upon another it is often found advantageous to bring them together in solution. The full explanation of this remains to be given. It appears highly probable that when a substance is dissolved in water some deep-seated change takes place in it, and that is the principal reason why substances in solution act upon each other so readily. This subject will be briefly discussed farther on.

Summary.—You have thus learned that

(1) Water can be decomposed into hydrogen and oxygen by means of an electric current;

(2) The gases are obtained in the proportion of eight parts by weight of oxygen to one part by weight of hydrogen, or one volume of oxygen to two volumes of hydrogen;

(3) When hydrogen is burned water is formed;

(4) When hydrogen and oxygen are mixed together they do not combine under ordinary circumstances;

(5) When a spark or flame is brought in contact with the mixture, violent action accompanied by explosion takes place;

(6) This action accompanies the chemical combination of the two gases;

(7) They combine in the same proportions as those in which they are obtained from water by the action of the electric current;

(8) Water can be made by passing hydrogen over heated copper oxide;

(9) By weighing the copper oxide before and after the experiment, and determining the weight of the water formed, it is found that eight ninths of the weight of the water is oxygen.

Formula of Water.—All the facts taken together prove that the composition of water is what it has been stated to be. Now, using the accepted combining weights of hydrogen and oxygen, viz., 1 and 16, the simplest formula which expresses the composition of water is H_2O. This expresses the fact that water is composed of 2 parts by weight of hydrogen and 16 parts by weight of oxygen, or 1 part of the former to 8 parts of the latter. If 8 were adopted as the combining weight of oxygen the formula of water would be HO.

Comparison of Hydrogen and Oxygen.—Hydrogen and oxygen are different kinds of matter, just as heat and electricity are different kinds of energy. Heat can be converted into electricity, and electricity into heat, but one element cannot by any means known to us be converted into another. They appear to be entirely independent of each other. If we compare hydrogen with oxygen we find very few facts that indicate any analogy between the two elements. In their physical properties they are, to be sure, similar. Both are transparent, colorless, inodorous gases. On the other hand, oxygen combines readily with a large number of substances with which hydrogen does not combine. Oxygen, as you have seen, combines easily with carbon, sulphur, phosphorus, and iron. It is a difficult matter to get any of these

elements to combine directly with hydrogen. Further, it is a general truth that substances that combine readily with hydrogen do not combine readily with oxygen. The two elements have opposite chemical properties. What one can do the other cannot do.

Opposite Chemical Properties are Favorable to Combination.—Not only do hydrogen and oxygen, with their opposite properties, combine with great ease under the proper conditions, but, as we shall see later, it is a general rule that elements of like properties do not readily combine with one another, while elements of unlike properties do readily combine with one another.

Ozone.—When electric sparks are passed for a time through oxygen it is changed in a remarkable way. It acquires a strong odor and is much more active than the substance which we call oxygen. The odor of the gas is noticed in the neighborhood of an electric machine in action, and is said to be noticed during thunder-storms. The substance which has the odor is *ozone*. It is formed in a number of chemical reactions, as when phosphorus acts on air in the presence of water. By cold and pressure it has been obtained in the form of a dark-blue liquid. Ozone is present in small quantities in the air.

Relation between Oxygen and Ozone.—When a certain volume of oxygen is converted into ozone the volume of gas is decreased to two thirds.

By heating ozone above 300° C. it is converted into ordinary oxygen, and its volume increased from two to three.

It is clear that the element oxygen can be converted into something else without the addition of anything to

it. This might lead you to think that it is not an element. But that which is formed from it has exactly the same weight and this can be changed back to oxygen without anything being added to it. It follows that the change must take place within the oxygen itself.

Hydrogen Dioxide, H_2O_2.—Besides water, hydrogen and oxygen form a second compound with each other. This is hydrogen dioxide, H_2O_2.* It is prepared by treating barium dioxide, BaO_2, with sulphuric acid. It is a liquid that decomposes easily into water and oxygen. The ease with which it gives up oxygen makes it a good *oxidizing agent*. It is now manufactured on a large scale, and is used in medicine.

* The reason for writing this formula H_2O_2 and not HO will be seen later.

CHAPTER IX.

COMPOUNDS OF NITROGEN WITH HYDROGEN AND OXYGEN.

Destructive Distillation of Animal and Vegetable Substances which Contain Nitrogen.—Whenever a compound containing carbon, hydrogen, and nitrogen is heated in a closed vessel, so that the air cannot reach it, and it cannot burn up, the nitrogen passes out of the compound, not as nitrogen, but partly at least in combination with hydrogen, as *ammonia.* Nearly all animal substances contain carbon, hydrogen, oxygen, and nitrogen, and many of them give off ammonia when heated in the way described. Heating in this way is called *destructive distillation.* Similarly, compounds containing carbon, oxygen, and hydrogen, even though they are thoroughly dry, when heated give off oxygen in combination with hydrogen as water (see Experiment 1). The coal that is used for making illuminating-gas contains some hydrogen and nitrogen in chemical combination, and when the coal is heated in a closed vessel ammonia is given off.

Natural Decomposition of Animal and Vegetable Substances that Contain Nitrogen.—The decay or slow natural decomposition of animal and vegetable substances exposed to the air is familiar to every one. It is caused by the

action of hosts of minute living things (called bacteria) acting together with the oxygen of the air. Some animal substances give off ammonia when they decompose in the air. When animal substances decompose under proper conditions either a nitrite or a nitrate is formed; the former is derived from nitrous acid, HNO_2, the latter from nitric acid, HNO_3. In some countries where the conditions are favorable to the process immense quantities of nitrates are found, chiefly potassium nitrate or salt-petre, KNO_3, and sodium nitrate or Chili saltpetre, $NaNO_3$, so called because it is found in Chili in large quantities. From the nitrates nitric acid can easily be obtained.

How Compounds of Nitrogen are Made.—The principal compounds of nitrogen are those which it forms with hydrogen and oxygen. They are made either from ammonia or from nitric acid by methods which will be described.

Ammonia, NH_3.—The conditions under which ammonia is formed have been mentioned. The chief sources at present are the " ammoniacal liquor " of the gas-works, which is the water through which the gas has been passed for the purpose of removing the ammonia, and refuse animal matter. By adding hydrochloric acid to this liquid *ammonium chloride*, commonly called *sal ammoniac*, is formed. This is the most common compound containing ammonia, and it is therefore used in the laboratory for making ammonia.

Preparation of Ammonia.

EXPERIMENT 50.—To a little ammonium chloride on a watch-glass add a few drops of a strong solution of caustic soda, and

notice the odor of the gas given off. Do the same thing with caustic potash. Mix small quantities of quicklime and ammonium chloride in a mortar, and notice the odor. Has ammonium chloride this odor ?

To prepare ammonia mix slaked lime and ammonium chloride in the proportion of 2 parts of the former to 1 part of the latter, and gently heat the mixture. It has been shown that besides the ammonia, which is given off in the form of gas, calcium chloride, $CaCl_2$, and water are formed in the reaction. It is represented thus:

$$2NH_4Cl + CaO_2H_2 = 2NH_3 + CaCl_2 + 2H_2O.$$
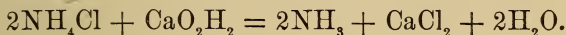
EXPERIMENT 51.—Arrange an apparatus as shown in Fig. 23, omitting, however, the funnel-tube ; a cork with one hole will therefore answer. Weigh 100 grams quicklime into a dish, and
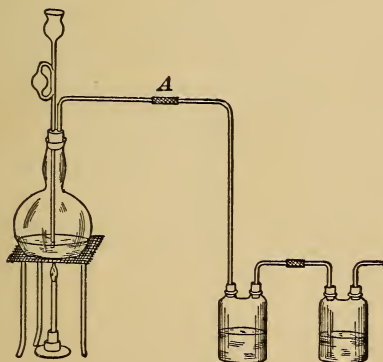
FIG. 23.

bring this into the flask. Add just enough water to slake it without making it moist, then add 50 grams ammonium chloride and mix by shaking. Push the stopper into place and gently heat the flask, which should rest upon a sand-bath. After the air is driven out, the gas will be completely absorbed by the water in the first Woulff's flask. Disconnect at *A*, and connect with another tube bent upward. Collect some of the escaping gas by

displacing air, *placing the vessel with the mouth downward,* as

the gas is much lighter than air.   The arrangement is shown in Fig. 24.   The vessel in which the gas is collected should be dry, as water absorbs ammonia very readily.   Hence also it cannot be collected over water.   In the gas collected introduce a burning stick or taper.   Does the gas burn ?   Does it support combustion ?   *In working with the gas great care must be taken to avoid breathing it in any quantity.*   After enough has been collected, connect the delivery-tube again with the series of Woulff's flasks,
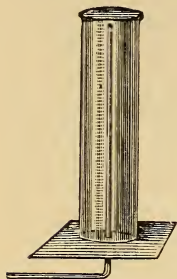
FIG. 24.

and pass the gas over the water as long as it is given off.

Properties of Ammonia.—From the observations made in the experiment just performed you see that ammonia is a colorless, transparent gas.   It has a very penetrating characteristic odor.   In concentrated form it causes suffocation.   It is but little more than half as heavy as air. It is easily converted into a liquid by pressure and cold.   When the pressure is removed from the liquefied ammonia it passes back to the form of gas.   In so doing it absorbs heat.   These facts are taken advantage of for the artificial preparation of ice.   Carré's ice-machine is used for this purpose.   Ammonia does not burn in the air, but does burn in oxygen.   It is absorbed by water in very large quantity.   One volume of water at the ordinary temperature dissolves about 600 volumes of ammonia-gas, and at 0° C. about 1000 volumes.

Ammonia-water.—The solution of ammonia in water is what we commonly have to deal with under the name ammonia.   In ordinary language it is sometimes called "spirits of hartshorn" and also "household ammonia." The solution loses all its gas when heated to the boiling temperature.

Nitric Acid, HNO_3.—To effect the direct union of nitrogen with oxygen and hydrogen is not easier than to effect the direct union of nitrogen and hydrogen to form ammonia. The silent and continuous action of minute organisms in the soil is always tending to transform the waste products of animal life into compounds closely related to nitric acid. In general, by oxidation the nitrogen of animal substances is converted into nitric acid, while by reduction it is converted into ammonia.

Preparation of Nitric Acid.—Nitric acid is obtained from a nitrate like potassium nitrate, KNO_3, or sodium nitrate, $NaNO_3$, by treating with sulphuric acid.

$$2NaNO_3 + H_2SO_4 = Na_2SO_4 + 2HNO_3.$$

Sodium and sulphuric give sodium and nitric
nitrate acid sulphate acid.
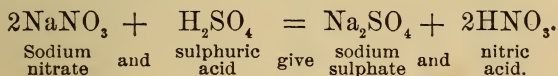
You see that the hydrogen of the sulphuric acid changes place with the sodium of the nitrate.

EXPERIMENT 52.—Arrange an apparatus as shown in Fig. 25. In the retort put 25 grams sodium nitrate (Chili saltpetre) and 15 grams concentrated sulphuric acid. On heating gently, nitric acid will distil over and be condensed in the receiver. In the latter stage of the operation the vessel becomes filled with a reddish-brown gas. The acid which is collected has a somewhat yellowish color.

Pure Nitric Acid is a colorless liquid. It gives off colorless fumes when exposed to the air. When boiled it undergoes slight decomposition into oxygen, water, and compounds of nitrogen and oxygen. One of these compounds is colored, and it is this which is noticed in the last experiment and whenever strong nitric acid is boiled. Nitric acid suffers a similar decomposition when exposed to the action of the direct rays of the sun. In conse-

quence of this decomposition bottles containing strong
nitric acid sometimes contain a reddish-brown gas above
the liquid after standing for some time. Strong nitric
acid acts violently on many substances, particularly those
of animal and vegetable origin, decomposing them. It
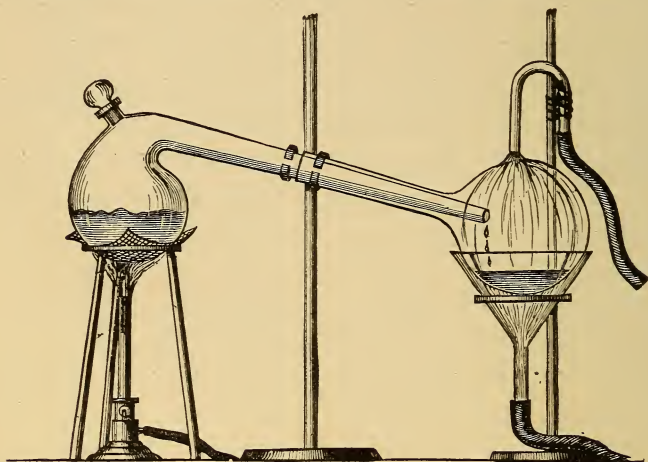
FIG. 25.

causes bad wounds in contact with the flesh; it eats
through clothing; it burns wood; it dissolves metals; and
it is altogether one of the most active of chemical sub-
stances. In working with it it is necessary to take the
greatest care.

Ordinary or Commercial Nitric Acid contains only about
68 per cent of the chemical compound HNO_3. The rest
is mostly water, though there are several impurities
present in small quantities.

How to Make Strong Nitric Acid.*—Pure, strong nitric

* The experiments with strong nitric acid may be performed or
not as the teacher thinks best. They had better not be performed
by the pupils, and should not be performed by any one who is not
experienced in working with chemical substances.

acid can be made by mixing commercial nitric acid and commercial strong sulphuric acid and distilling.

EXPERIMENT 53.—Mix together 400 grams ordinary concentrated sulphuric acid and 80 grams ordinary concentrated nitric acid. Distil the mixture *slowly* from a retort arranged as in Experiment 52, taking care to keep the neck of the retort cool by placing filter-paper moistened with cold water on it. Use the acid thus obtained for the purpose of studying the properties of pure nitric acid.

Nitric Acid Gives up Oxygen Readily.—Nitric acid is much used on account of the ease with which it gives up oxygen. Many substances burn up in strong nitric acid.

EXPERIMENT 54.—Pour concentrated nitric acid into a wide test-tube, so that it is about one fourth filled. Heat the end of a stick
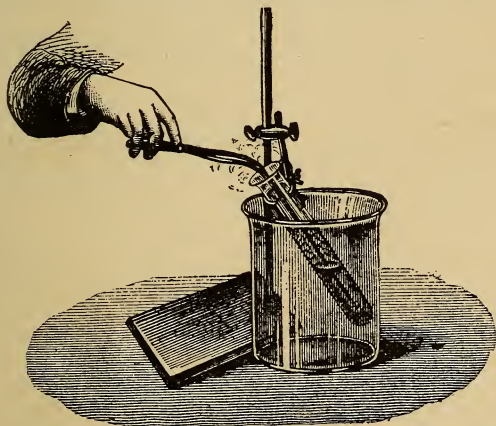
FIG. 26.

of charcoal of about the size of a lead-pencil, and, holding the other end with a forceps, introduce the heated end into the acid. It will continue to burn with a bright light, even though it be placed below the surface of the liquid. The action is oxidation. The charcoal in this case finds the oxygen in the acid and not in the air. Great care must be taken in performing this experiment. The charcoal should not come in contact with the sides of the

test-tube. A large beaker-glass should be placed beneath the test-tube, so that in case the tube should break, the acid would be caught and prevented from doing harm. The arrangement of the apparatus is shown in Fig. 26. The gases given off from the tube are offensive and poisonous. Hence this as well as all other experiments with strong nitric acid should be carried on either out of doors or under a hood in which the draught is good.

EXPERIMENT 55.—In a small flask put a few pieces of granulated tin. Pour on this just enough strong nitric acid to cover it. Heat gently over a small flame. What takes place? What is the appearance of the substance left in the flask? It is mostly a compound of tin and oxygen. (See Experiment 7.)

Action of Nitric Acid upon Some Metals.—Generally when an acid acts upon a metallic element like silver, copper, lead, etc., the hydrogen of the acid is liberated and the metallic element takes its place. Thus when nitric acid acts upon silver the action takes place as represented in the equation

$$Ag \ + \ HNO_3 \ = \ AgNO_3 \ + \ H.$$
Silver and nitric acid give silver nitrate and hydrogen.
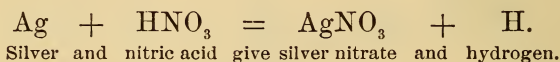
The substances thus formed are called *nitrates*. At the same time the hydrogen and a part of the oxygen are taken out of the acid, and compounds of nitrogen and oxygen are formed which are represented by the formulas NO_2, NO, and N_2O. The first of these, nitrogen peroxide, NO_2, is a colored gas, and as some of it is always formed when nitric acid acts upon metals in the air, the presence of the reddish-brown gas observed in the experiments already performed with nitric acid will be readily understood.

EXPERIMENT 56 —Dissolve a few pieces of copper-foil in ordinary commercial nitric acid diluted with about half its volume of water. The operation should be carried on in a good-sized flask and either out of doors or under a good hood. What action takes

place ? After the action is over what is the appearance of the liquid in the flask ? Pour it out and evaporate under a hood to crystallization. Compare the substance thus obtained with copper nitrate.—Heat specimens of each.—Treat small specimens with sulphuric acid.—Do the substances appear to be identical ? What reasons have you for considering them identical ?

Aqua Regia is made by mixing together concentrated nitric and hydrochloric acid. It is an excellent solvent. It is called *aqua regia* because it dissolves the king of metals, gold. Similarly nitric acid is called *aqua fortis*, or strong water. In olden times all liquids were regarded as kinds of water, and all gases as kinds of air.

The Oxides of Nitrogen.—Nitrogen combines with oxygen in five proportions. The names and symbols of the compounds formed are here given:

Nitrous oxide.................................N_2O
Nitric oxide...........................NO or N_2O_2
Nitrogen trioxide................................N_2O_3
Nitrogen peroxide......................... NO_2 or N_2O_4
Nitrogen pentoxide..............................N_2O_5

A Good Illustration of the Law of Multiple Proportions. —The combining weight of nitrogen being 14, the above symbols represent the fact that in the compounds of nitrogen and oxygen the quantities of oxygen combined with 28 parts of nitrogen are 16, 32, 48, 64, and 80; or 16, twice 16, three times 16, four times 16, and five times 16 parts of oxygen are combined with 28 parts by weight of nitrogen. This series of compounds is an excellent illustration of the law of multiple proportions, which is one of the most important and interesting truths of chemistry.—[What is the law of multiple proportions ? How does this series illustrate it ?]

Nitrous Oxide, N_2O.—This compound is formed by reduction of nitric acid when the acid acts upon metals under favorable conditions of concentration and temperature. It is usually prepared by heating ammonium nitrate. The decomposition takes place as represented, thus:

$$NH_4NO_3 \quad = \quad N_2O \quad + \quad 2H_2O$$

Ammonium nitrate   heated gives   nitrous oxide   and   water.
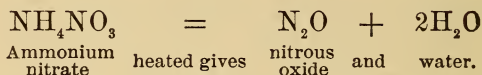
EXPERIMENT 57.—In a retort heat 10 to 15 grams crystallized ammonium nitrate until it has the appearance of boiling. Do not heat higher than is necessary to secure a regular evolution of gas. Connect a wide rubber tube directly with the neck of the retort, and collect the gas over water, as in the case of oxygen.

Properties of Nitrous Oxide.—It is colorless and transparent and has a slightly sweetish taste. When inhaled it causes a kind of intoxication, which is apt to show itself in the form of hysterical laughing. Hence the gas is commonly called *laughing-gas*. Inhaled in larger quantity it causes unconsciousness and insensibility to pain. It is therefore used in certain surgical operations, particularly in pulling teeth. It supports combustion almost as well as pure oxygen.

EXPERIMENT 58.—Insert into it a piece of burning wood, a candle, and a small piece of phosphorus.

Nitric Oxide, NO.—This gas, as has been stated, is formed when nitric acid acts upon some metals, as copper. It seems probable that two changes take place:

(1) Nitric oxide, water, and copper oxide are formed as represented in the equation

$$2HNO_3 \quad + \quad 3Cu \quad = \quad H_2O \quad + \quad 3CuO \quad + \quad 2NO.$$

Nitric acid   and copper give   water   and   copper oxide   and   nitric oxide.

(2) Then the copper oxide forms copper nitrate with some of the acid, and this nitrate dissolves:

$$CuO + 2HNO_3 = Cu(NO_3)_2 + H_2O.$$

Copper and nitric acid give copper and water.
oxide   nitrate

The complete action is represented by the equation

$$8HNO_3 + 3Cu = 3Cu(NO_3)_2 + 4H_2O + 2NO.$$

EXPERIMENT 59.—Arrange an apparatus as shown in Fig. 27.
In the flask put a few pieces of copper-foil.
Cover this with water. Now add slowly, waiting each time, ordinary concentrated nitric acid. When enough acid has been added gas will be given off. If the acid is added quickly it not infrequently happens that the evolution of gas takes place too rapidly, so that the liquid is forced out of the flask through the funnel-tube. This can be avoided by not being in a hurry. What is the color of the gas in the flask at first? What is it after the action has continued for a short time? Fill two or three vessels with the gas over water.

FIG. 27.

Properties of Nitric Oxide.—Nitric oxide is a colorless, transparent gas. Its most remarkable property is its power to combine directly with oxygen when the two are brought together. The reaction is represented by the equation

$$NO + O = NO_2.$$

The product is nitrogen peroxide, and this at ordinary temperatures is a reddish-brown gas.

EXPERIMENT 60.—Turn one of the vessels containing colorless nitric oxide with the mouth upward and uncover it. What takes place? Explain the appearance of the colored gas in Experiment 59, and the fact that it afterward disappeared. What was in the vessel at the beginning of the operation? *Do not inhale the gas.*

Perform the experiment with nitric oxide where there is a good draught.

EXPERIMENT 61.—Into one of the vessels containing nitric oxide insert a burning candle. Does the gas burn? Does it support combustion?

Nitric oxide does not burn and does not support combustion.

Nitrogen Peroxide, NO_2.—This is the reddish-brown gas formed in the experiments with nitric oxide. It has a disagreeable smell and is poisonous. It is used in large quantities in the manufacture of the extremely important substance sulphuric acid, as will be explained farther on.

CHAPTER X.

CHLORINE AND ITS COMPOUNDS WITH HYDROGEN AND OXYGEN.

Introductory.—A little later you will see that oxygen and nitrogen are members of families of elements. The other members of the oxygen family resemble oxygen in many respects, and the other members of the nitrogen family resemble nitrogen. Hydrogen, strange to say, does not belong to any family but stands by itself. Another family is the chlorine family, of which chlorine is the best-known member.

Occurrence of Chlorine.—Chlorine, though widely distributed in nature, does not occur in very large quantity as compared with oxygen and hydrogen. It is found chiefly in combination with the element sodium as common salt or sodium chloride, which is represented by the symbol NaCl. It is also found in combination with other elements, as potassium, magnesium, etc. In small quantity it occurs in combination with silver, forming a valuable ore of silver. All the chlorine with which we have to deal is made from common salt.

Preparation of Chlorine.—The simplest method of preparing chlorine and the one that is almost exclusively used on the large scale consists in passing an electric

current through a water solution of potassium chloride. This causes chlorine to appear at one pole of the battery and potassium at the other. The chlorine escapes as such, while the potassium acts upon the water, forming hydrogen and potassium hydroxide or caustic potash. Chlorine is also obtained by the action of an electric current on a solution of zinc chloride and on molten sodium chloride.

In the laboratory chlorine is made by oxidizing hydrochloric acid. Under proper conditions the action represented in the following equation takes place:

$$2HCl \quad + \quad O \quad = \quad H_2O \quad + \quad 2Cl.$$

<small>Hydrochloric acid   and oxygen give   water   and chlorine.</small>
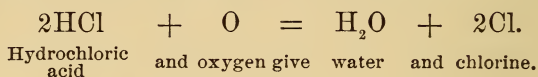
Laboratory Method.—In the laboratory it is most convenient to bring together ordinary hydrochloric acid and manganese dioxide, MnO_2, a substance which you have already had to deal with in preparing oxygen. The action which takes place is represented thus:

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + 2Cl.$$
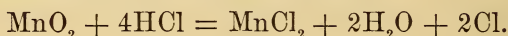
Commercial Manufacture of Chlorine.—Chlorine is an important article of commerce, as it finds extensive use for bleaching and disinfecting. As manganese dioxide is a comparatively expensive substance, efforts have been made to devise some cheaper method of preparation than that just mentioned. Up to recently two methods have been extensively used. They are:

(1) *Deacon's Process.*—This consists in passing air and hydrochloric acid together through a heated tube containing clay balls which have been saturated with a solution of copper sulphate or blue vitriol. Exactly why the

oxidation should take place under these circumstances is not known. The main part of the action is the oxidation of the hydrochloric acid, as represented in the above equation.

(2) *Weldon's Process.*—This consists, in the first place, in making the chlorine from manganese dioxide and hydrochloric acid, and then, instead of throwing away the liquid contained in the vessel, mainly manganese chloride, $MnCl_2$, in solution, this is treated with steam, lime, and air, and thus converted into a substance that acts towards hydrochloric acid like manganese dioxide, setting chlorine free.

These methods have been largely supplanted by that referred to in the paragraph "Preparation of Chlorine." This is the *electrolytic process.*
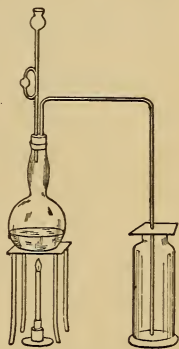
Fig. 28.

EXPERIMENT 62.—In a flask put about 100 grams (3 to 4 ounces) of black oxide of manganese. Pour upon it enough ordinary concentrated hydrochloric acid to cover it completely. Arrange the apparatus as shown in Fig. 28. Heat gently in a sand-bath, when chlorine will be given off. Collect six or eight *dry* cylinders or bottles full of chlorine by letting the delivery-tube extend to the bottom of the collecting vessel and covering the mouth of the vessel with a piece of paper. You can see when the vessel is full by the color of the gas.—*The experiments with chlorine should be carried on in a place where the draught is good. Do not inhale the gas.*

(1) Into one of the vessels containing chlorine introduce a little finely powdered antimony. The two elements combine at once with evolution of light and heat. [In what respect does this experiment resemble the one in which iron was burned in oxygen ?]

(2) Into a second vessel introduce a few pieces of heated cop-

per-foil.   Combination takes place with evolution of light and heat.   A compound of copper and chlorine is formed.

(3) Into a third vessel introduce a piece of paper with writing on it, some flowers, and pieces of colored calico.   Most of the colors will be destroyed *if the substances are moist.*

(4) Into a fourth vessel introduce a dry piece of the same colored calico as that used in (3).   The dry piece is not bleached; the moist piece is.

Properties of Chlorine.—Chlorine is a greenish-yellow gas.   It has a disagreeable smell, and acts upon the passages of the throat and nose, causing irritation and inflammation.   The feeling produced is much like that of "a cold in the head."   Inhaled in concentrated form, that is, not diluted with a great deal of air, it would cause death.   It is much heavier than air.   Its specific gravity is 2.49.   A litre of chlorine gas at 0° C. and atmospheric pressure weighs 3.22 grams.   It is soluble in water and acts upon mercury, and therefore must be collected by displacement of air.   It combines readily with other substances and destroys colors or bleaches.   It is one of the most active elements.   In bleaching it decomposes the colored substances and forms colorless substances.   It is used to disinfect substances.

Disinfection.—Substances given off from persons sick with some diseases, such as typhoid fever, smallpox, etc., are apt to cause the same diseases in well persons.   It is therefore desirable to destroy them.   This is called disinfecting.   One of the most valuable substances for this purpose is chlorine.   It is sold in the form of "bleaching-powder," known also as "chloride of lime," which is a compound made by passing chlorine gas into slaked lime. A solution of this substance in water is a valuable dis-

infectant.   Old drains, sinks, etc., from which bad odors arise may be freed from their odors and rendered harmless by adding enough of such a solution.

Combination of Hydrogen and Chlorine.—Just as hydrogen burns in the air it burns also in chlorine.

EXPERIMENT 63.—Light a jet of hydrogen in the air and carefully introduce it into a vessel containing chlorine. Does it continue to burn ? What is the appearance of the flame ? What evidence have you that a product is formed ? Test the gas remaining in the jar with blue litmus solution shaken up in it, and compare with the action of chlorine gas on the solution.

The burning of hydrogen in air or oxygen is, as you have seen, the act of combination of hydrogen and oxygen, the product being water in the state of vapor, and therefore invisible.   When hydrogen burns in chlorine the action consists in the union of the two gases, the product being hydrochloric acid, HCl, which forms clouds in the air.   In both cases the action is accompanied by heat and light.

Chlorides.—Just as the compounds of oxygen with other elements are called *oxides*, so the compounds of chlorine with the elements are called *chlorides*.

Hydrochloric Acid, HCl.—The only compound which chlorine and hydrogen form with each other is hydrochloric acid.   It has already been shown that hydrogen burns in chlorine, and that hydrochloric acid is formed. The two gases may be mixed together and allowed to stand together indefinitely in the dark, and no action will take place.   If, however, the mixture is put in a room lighted by the sun, but where the sun does not shine directly upon it, combination takes place gradually; and if the sun is allowed to shine upon the mixture for an

instant, explosion occurs, and this is the sign of the combination of the two gases. The same sudden combination is effected by applying a flame or spark to the mixture. In this case *light causes chemical action.* The art of photography depends upon the fact that light has the power to cause chemical changes, as will be more fully explained later. It should be specially noted that the cause of the chemical changes in the cases referred to is not the heat but the light. If the substances are heated to the same temperature in the dark, the changes do not take place.

Preparation of Hydrochloric Acid.

EXPERIMENT 64.—Pour 2 or 3 c.c. concentrated sulphuric acid on a gram or two of common salt in a test-tube. What takes place? Is a gas given off? What is its appearance?

Hydrochloric acid is always made by treating common salt with sulphuric acid, when the reaction takes place which is represented in the equation

$$2NaCl \ + \ H_2SO_4 \ = \ Na_2SO_4 \ + \ 2HCl.$$

Sodium chloride   and   sulphuric acid   give   sodium sulphate   and   hydrochloric acid.
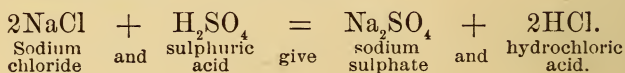
The products are sodium sulphate and hydrochloric acid. The hydrochloric acid is given off as a gas, and the sodium sulphate remains behind in the flask.

EXPERIMENT 65.—Arrange an apparatus as shown in Fig. 23, page 73. Weigh out, separately, 100 grams common salt, 100 grams concentrated sulphuric acid, and 20 c.c. water. Mix the acid and water, taking the usual precautions (see note p. 51). Let the mixture cool down to the ordinary temperature, and then pour it on the salt in the flask. Now heat the flask gently, and the gas will be regularly given off. Conduct it at first over water contained in two or three Woulff's bottles until what passes over is completely absorbed in the first Woulff's bottle. When the air has been displaced, the gas is all absorbed as soon as

it comes in contact with the water.—After the gas has passed for ten to fifteen minutes disconnect at *A* (see Fig. 23). Notice the fumes. These become denser by " blowing the breath " upon them. Apply a lighted match to the end of the tube. Does the gas burn ? Collect some of the gas in a dry cylinder by displacement of air, as in the case of chlorine. The specific gravity of the gas being 1.26, the vessel must of course be placed with the mouth upward. Has the gas any color ? Is it transparent ? Insert a burning stick or candle in the cylinder filled with the gas. Does the gas support combustion ?—Connect the generating-flask again with the bottles containing water, and let the process continue until no more gas comes over. The reaction represented in the equation

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$$

is now complete. After the flask has cooled down pour water on the contents, and when the substance is dissolved filter it and evaporate to such a concentration that, on cooling, the sodium sulphate is deposited. Pour off the liquid, and dry the solid substance by placing it upon folds of filter-paper. Compare the substance with the common salt which you put in the flask before the experiment. What proofs have you that the two substances are not the same ? Heat a small piece of each in a dry tube closed at one end. What differences do you notice ?—Treat a small piece of each in a test-tube with a little concentrated sulphuric acid. What difference do you notice ?—If in the experiment you should recover all the sodium sulphate formed, how much would you have ? [The combining weight of sodium is 23 ; of sulphur, 32; and of chlorine 35.5.] The relations between the quantities of the substances that take part in the reaction are expressed as follows:

2NaCl	+	H₂SO₄	=	Na₂SO₄
2(23 + 35.5)		2 × 1 + 32 + 4 × 16		2 × 23 + 32 + 4 × 16
117 parts	+	98 parts	=	142 parts

$$+ \quad 2HCl.$$
$$2(1 + 35.5).$$
$$+ \quad 73 \text{ parts.}$$
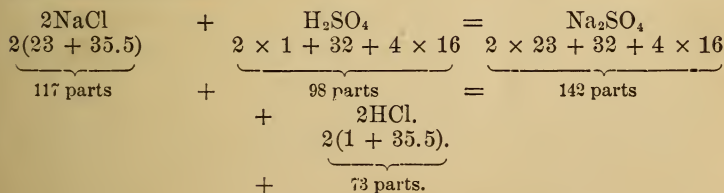
The quantity of sodium sulphate formed is to the quantity of sodium chloride as 142 is to 117. Therefore if you use 100 grams

of sodium chloride, the quantity of sodium sulphate formed is found by solving the simple proportion:

$$117 : 100 :: 142 : \text{grams of sodium sulphate.}$$

—Put about 50 c.c. of the liquid from the first Woulff's bottle in a porcelain evaporating-dish. Heat over a small flame just to boiling. Is hydrochloric acid given off? Can all the liquid be driven off by boiling?—Try the action of the solution on some iron filings. Is a gas given off? What is it?—Add some to a little granulated zinc in a test-tube? Is hydrogen given off?— Add some to a little manganese dioxide in a test-tube. Is chlorine given off?—Add ten or twelve drops of the acid to 2 or 3 c.c. water in a test-tube. Taste the dilute solution. How would you describe the taste?—Add a drop or two of a solution of *blue* litmus, or put into it a piece of paper colored *blue* with litmus. Litmus is a vegetable color prepared for use as a dye. Other vegetable colors are changed by hydrochloric acid.—The color will be restored by adding a few drops of caustic soda or ammonia.

Composition of Hydrochloric Acid.—That hydrochloric acid consists of hydrogen and chlorine is shown by the fact that it is formed when hydrogen combines with chlorine. It has further been shown that when the two gases combine they do so in equal volumes, 1 volume of hydrogen combining with 1 volume of chlorine; and these 2 volumes form 2 volumes of hydrochloric-acid gas. In 36.5 parts by weight of hydrochloric-acid gas there are contained 1 part by weight of hydrogen and 35.5 parts by weight of chlorine. The combining weight of chlorine being 35.5, the composition of hydrochloric-acid gas is represented by the symbol HCl.

Chemical Conduct of Hydrochloric Acid.—1. Hydrochloric acid gives up its hydrogen when brought in contact with certain substances like iron, zinc, etc., which belong to the class called metals; and it takes up these metallic

elements in place of the hydrogen. Thus zinc and hydrochloric acid give zinc chloride and hydrogen:

$$Zn + 2HCl = ZnCl_2 + 2H.$$
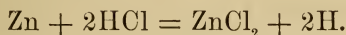
2. In contact with substances which give up oxygen, or with oxygen itself under certain circumstances, it gives up its chlorine, while the hydrogen combines with oxygen to form water:

$$2HCl + O = H_2O + 2Cl.$$
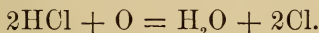
3. When it acts upon metallic oxides or compounds of the metals with oxygen, such as magnesia or magnesium oxide, MgO; lime or calcium oxide, CaO; zinc oxide, ZnO, etc.,—compounds which do not easily give up their oxygen,—the hydrogen of the acid combines with the oxygen of the oxide to form water, while the metals combine with the chlorine:

$$MgO + 2HCl = MgCl_2 + H_2O;$$
$$CaO + 2HCl = CaCl_2 + H_2O;$$
$$ZnO + 2HCl = ZnCl_2 + H_2O.$$
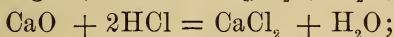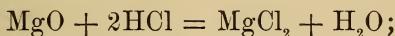
Compounds of Chlorine with Oxygen and with Hydrogen and Oxygen.—As you have seen, chlorine combines very readily with hydrogen, and hydrogen with oxygen, and the products are stable compounds. On the other hand, chlorine does not combine directly with oxygen. Indirectly the two elements can be made to combine, but the compounds decompose very easily into the elements.

Compounds of Chlorine with Hydrogen and Oxygen.— The principal reaction made use of for the preparation of compounds of chlorine, oxygen, and hydrogen consists in treating caustic potash or potassium hydroxide, KOH,

with chlorine. If the solution of caustic potash is warm and concentrated the reaction takes place mainly as represented in this equation:

$$6KOH + 6Cl = 5KCl + KClO_3 + 3H_2O.$$

The compound KCl is *potassium chloride;* $KClO_3$ is the well-known substance *potassium chlorate,* or chlorate of potash, used for making oxygen in Experiments 20 and 21.

If the solution is dilute the reaction takes place thus:

$$2KOH + 2Cl = KCl + KClO + H_2O.$$

The product KClO is known as *potassium hypochlorite.*

Hypochlorous Acid, HClO, and Chloric Acid, $HClO_3$.— Just as sodium nitrate, $NaNO_3$, yields nitric acid, HNO_3, when treated with sulphuric acid (see Experiment 52); and sodium chloride, NaCl, yields hydrochloric acid, HCl (see Experiment 65); so potassium chlorate, $KClO_3$, yields *chloric acid,* $HClO_3$; and potassium hypochlorite, KClO, yields *hypochlorous acid,* HClO:

$$2NaNO_3 + H_2SO_4 = 2HNO_3 + Na_2SO_4;$$
$$2NaCl \quad + H_2SO_4 = 2HCl \quad + Na_2SO_4;$$
$$2KClO_3 + H_2SO_4 = 2HClO_3 + K_2SO_4;$$
$$2KClO \quad + H_2SO_4 = 2HClO \quad + K_2SO_4.$$
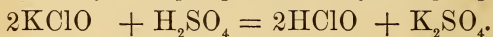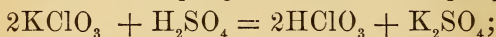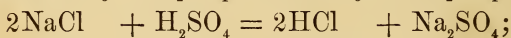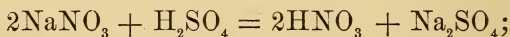
Bleaching-powder, or "*chloride of lime,*" is a substance similar to potassium hypochlorite, and is formed by passing chlorine into slaked lime. It will be more fully considered under Calcium.

Other Compounds of Chlorine, Hydrogen, and Oxygen.— There are four compounds of chlorine, hydrogen, and oxygen. As far as composition is concerned, they bear a

simple relation to one another. Beginning with hydro-chloric acid, we have a series of compounds the successive members of which differ by one combining weight of oxygen:

Hydrochloric acid........................... HCl.
Hypochlorous acid .... HClO.
Chlorous acid............................... $HClO_2$.
Chloric acid................................ $HClO_3$
Perchloric acid............................. $HClO_4$.

This series, like the series of compounds of nitrogen and oxygen, illustrates very clearly the *law of multiple proportions*. [What is the law of multiple proportions? In what way does this series illustrate the law?]

CHAPTER XI.

ACIDS—BASES—NEUTRALIZATION—SALTS.

Introduction.—You have already met with a number of substances called acids. It is now time to inquire what these substances have in common that lead chemists to call them all acids. What is there in common, for example, between the heavy, oily liquid sulphuric acid and the colorless gas hydrochloric acid? It is not possible to understand the nature of their common properties without reference to a class of substances to which special attention will be called in due time. These are the *alkalies,* which are the most marked members of a class of substances known as *bases.* Acids and bases have the power to destroy the characteristic properties of each other. When an acid is brought in contact with a base in proper proportions, the characteristic properties of both the acid and the base are destroyed. They are said to *neutralize* each other.

A Study of Neutralization.—The most common acids are sulphuric, hydrochloric, and nitric acids. Among the more common bases are caustic soda, caustic potash, and lime. A convenient way to recognize whether a substance has acid or basic properties is by means of certain color-changes. The dye litmus is blue. If a solution that is colored blue with litmus is treated with a drop or two of an acid, the color is changed to red. If now the red

solution is treated with a few drops of a solution of a base, the blue color is restored. There are many other substances which change markedly in color, according to whether the solutions in which they are present are acid or basic. An infusion of red cabbage, for example, changes color when treated with an acid, and recovers its color when treated with an alkali.

EXPERIMENT 66.—Make dilute solutions of nitric, hydrochloric, and sulphuric acids (4 c.c. dilute acid, such as is used in the laboratory, to about 200 c.c. of water), and of caustic soda or caustic potash (about 1 gram to 200 c.c. of water). Measure off a definite quantity, say 20 c.c., of each of the acid solutions. Add a few drops of a solution of blue litmus. Gradually add to each of the measured quantities of acid sufficient dilute caustic soda to cause the red color just to change to blue. As long as the solution is red it is acid. When it turns blue it is alkaline. At the turning-point it is neutral. The experiment is best performed with the aid of a burette, which is a graduated tube with an opening from which small quantities can be poured. A convenient shape is that represented in Fig. 29. At the lower end is a small opening. The flow of the liquid from the burette is controlled by means of a small pinch-cock. It will require some practice to enable you to know exactly when the red color disappears and the blue appears, but with practice the point can be recognized with accuracy. Should too much alkali be allowed to get into the acid, add a small measured quantity of the acid from another burette. In one experiment
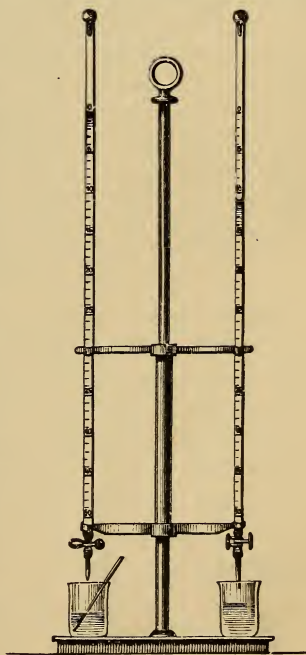
FIG. 29.

neutralize 20 c.c. of the acid; in a second 10 c.c.; in a third 15 c.c.—What relation do the quantities of alkali used bear to one another?—Does it always require a definite quantity of alkali to neutralize a certain quantity of acid?

What is Formed when an Acid Neutralizes a Base?— To determine this we may use in larger quantities the same substances as those used in the preceding experiments.

EXPERIMENT 67.—(1) Dissolve 10 grams caustic soda in 100 c.c. water. Add hydrochloric acid slowly, examining the solution from time to time by means of a piece of paper colored blue with litmus. As long as the solution is alkaline it will cause no change in the color of the paper. The instant it passes the point of neutralization it changes the color of the paper red. When this point is reached, evaporate the water on a water-bath to complete dryness, and see what is left.—Taste the substance. Has it an acid taste? Does it suggest any familiar substance? If it is common salt or sodium chloride, how ought it to conduct itself when treated with concentrated sulphuric acid? Does it conduct itself in this way? Is the substance an alkali? Is it an acid? Is it neutral? Its formation took place according to the equation

$$HCl + NaOH = NaCl + H_2O.$$
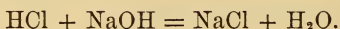
2. Perform the same experiment, using nitric acid instead of hydrochloric acid.—Compare the product with sodium nitrate. Heat a small specimen of each in a tube closed at one end. What takes place? Heat a small specimen of each with a little concentrated sulphuric acid in test-tubes. What takes place? The reaction between nitric acid and caustic soda is represented thus:

$$HNO_3 + NaOH = NaNO_3 + H_2O.$$
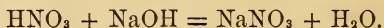
3 Similarly, sulphuric acid and caustic soda give sodium sulphate and water, thus:

$$H_2SO_4 + 2NaOH = Na_2SO_4 + 2H_2O.$$
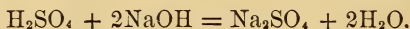
4. Similar reactions take place with caustic potash. Hydrochloric acid and caustic potash yield potassium chloride and water:

$$HCl + KOH = KCl + H_2O.$$
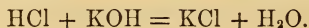
Nitric acid and caustic potash yield potassium nitrate and water :
$$HNO_3 + KOH = KNO_3 + H_2O.$$
Sulphuric acid and caustic potash yield potassium sulphate and water :
$$H_2SO_4 + 2KOH = K_2SO_4 + 2H_2O.$$
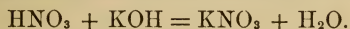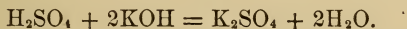
What these Experiments Show.—Considering the facts just learned, you see

(1) That an acid contains hydrogen;

(2) That a base contains a metal;

(3) That when an acid acts upon a base the hydrogen and the metal exchange places;

(4) That the substance obtained from the acid by replacing the hydrogen by a metal is neutral;

(5) That the substance formed by replacing the metal of the base by hydrogen is water.

The Fourth Statement not General.—All these statements except the fourth are true of all cases. In some cases after substituting a metallic element for the hydrogen of an acid, the substance has an alkaline reaction; and in other cases the product has an acid reaction.

Products Formed when a Metal Acts upon an Acid.— You have already seen that hydrochloric acid and sulphuric acid act upon certain metals, as iron and zinc, and that the action consists in giving up hydrogen and taking up metal in its place. The products of this action are the same in character as those formed by the action of acids on bases.

Acids, Bases, and Salts.—An *acid* is a substance containing hydrogen, which it easily exchanges for a metal when treated with a metal itself, or with a compound of a metal called a base.

A *base* is a substance containing a metal combined with

hydrogen and oxygen. It easily exchanges its metal for hydrogen when treated with an acid.

The products of the action of an acid on a base are, first, water, and, second, a neutral substance called a *salt*. In the examples already given, sodium chloride, potassium chloride, sodium nitrate, potassium nitrate, sodium sulphate, and potassium sulphate are salts.

What is a Metal?—Unfortunately it is not an easy thing to give a satisfactory answer to this question. We can give examples of metals, such as iron, zinc, silver, calcium, magnesium, etc.; but when we attempt to discover the common properties of these substances we are somewhat at a loss. In general, any element which has the power to enter into an acid in the place of the hydrogen is called a metal. With hydrogen and oxygen a metal forms a product which has the power to neutralize acids; that is to say, which has basic properties.

Importance of Water in the Experiments on Neutralization.—One fact of great importance is not taken into account in what has thus far been said about neutralization. It is thus: *The substances must be brought together in solution.* Dry hydrochloric acid and dry sodium hydroxide, for example, do not act upon each other, and the same is true of other perfectly dry acids and bases. *The water is essential to the action.* This raises the question:

What is Solution?—No satisfactory answer can yet be given to this question. There are many liquids besides water in which solids can be dissolved, but for the present attention may be confined to solutions in water. Of these there are two kinds:

(1) The solutions of some substances have the power to conduct electricity;

(2) The solutions of other substances have not this power.

Substances of the first class are called *electrolytes*. To this class belong acids, bases, and salts.

Substances of the second class are called *non-electrolytes*. To this class belong sugar and many other substances less familiar.

There is good reason for believing that, when an electrolyte is dissolved in water, a part of the substance is broken down or *dissociated* into simpler parts called *ions*. Thus, hydrochloric acid is believed to break down to a greater or less extent into the ions H and Cl; nitric acid into the ions H and NO_3, etc. So also, sodium hydroxide is believed to break down into the ions Na and OH; potassium hydroxide into the ions K and OH. Further, sodium chloride is believed to break down into the ions Na and Cl; potassium nitrate into the ions K and NO_3, etc.

The extent of this breaking down or dissociation (called electrolytic dissociation) is determined largely by the dilution—the greater the dilution the greater the dissociation.

Ions not the Same as Atoms.—The ions that are believed to be present in the solutions of electrolytes are not to be confounded with the atoms or with definite compounds. The atoms (see Atomic Theory) of which the smallest particle of hydrochloric acid is believed to be made up are, to be sure, hydrogen and chlorine. The ions into which the molecule of hydrochloric acid breaks down or

L. of C.

dissociates when dissolved in water are these atoms highly charged with electricity. When the electricity is discharged the elements appear in their ordinary forms.

Definition of Acids and Bases in Terms of the Theory of Electrolytic Dissociation.—If the views above presented are correct, and the evidence upon which they rest is undoubtedly strong, then acids and bases should be defined as follows:

(1) An acid is a substance that gives hydrogen ions when dissolved in water. *

(2) A base is a substance that gives ions of the composition represented by the formula OH, called *hydroxyl*, when dissolved in water.

The common properties of acids—the sour taste, the evolution of hydrogen when brought together with metals, their action on dyes, their power to neutralize bases—are believed to be due to the fact that they all give *hydrogen ions*.

So also the common properties of bases—their alkaline taste, their action on dyes, their power to neutralize acids—are believed to be due to the fact that they give *hydroxyl ions*.

Products of Neutralization.—In the light of the above ideas what conception are we to form of the act of neutralization? When, for example, hydrochloric acid and sodium hydroxide are brought together in solution what are the changes? Hydrochloric acid gives the ions H and Cl; sodium hydroxide gives the ions Na and OH. So that at first the water solution contains the ions

$$H + Cl + Na + OH.$$
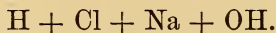
* Some other solvents act like water, but not in so marked a way.

But water has not the power to dissociate water; and if the constituents of water, the ions H and OH, find themselves together, they unite to form water. We should, therefore, have

$$H + Cl + Na + HO = Cl + Na + H_2O.$$
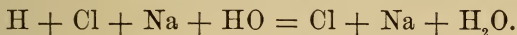
The characteristic hydrogen ion of the acid and the characteristic hydroxyl ion of the base would thus be removed and a condition of neutrality would result. The ions Cl and Na would remain uncombined unless the solution were concentrated. By evaporating off the water they would come more and more into combination, and with the disappearance of the water they would wholly disappear as such, and in their place we should have the compound sodium chloride.

Names of Acids.— The termination *ic* is generally used in naming acids, as is seen in the names hydrochloric, sulphuric, nitric, etc. If a second acid containing the same elements exists and the proportion of oxygen contained in it is smaller than in the acid the name of which ends in *ic*, the second acid is given a name ending in *ous*. Thus, *chlorous acid*, $HClO_2$, contains a smaller proportion of oxygen than *chloric acid*, $HClO_3$.

When more than two acids containing the same elements are known, prefixes are used to distinguish them. In the series of chlorine acids already referred to (see page 93) there is one acid which, so far as the proportion of oxygen contained in it is concerned, stands below chlorous acid. It is called *hypo*chlorous acid, the prefix *hypo* being derived from a Greek word meaning under. Further, there is an acid which contains a larger proportion of

oxygen than chloric acid. It is called *per*chloric acid, the Latin prefix *per* meaning here very or fully. It will be seen that the names of the acids vary with the proportion of oxygen contained in them.

Names of Bases.—As already stated, a base is a compound of a metal with hydrogen and oxygen or *hydroxyl*, HO. Thus caustic soda has the formula NaOH, caustic potash KOH, lime $Ca(OH)_2$, etc. They are commonly known as hydroxides. To distinguish between the hydroxides of the different metals, the names of the metals are put before the name hydroxide. Thus, caustic soda, NaOH, is called *sodium hydroxide;* caustic potash, KOH, is called *potassium hydroxide;* slaked lime, $Ca(OH)_2$, is called *calcium hydroxide*, etc. These compounds are called *hydrates* by some chemists.

Names of Salts.—The salts derived from a given acid receive a general name, and this general name is qualified in each case by the name of the metal contained in the salt. Thus, all the salts derived from nitric acid are called *nitrates;* all those derived from chloric acid are called *chlorates;* those derived from sulphuric acid are called *sulphates*. So too, further, the salts of chlorous acid are called *chlorites;* those of nitrous acid, *nitrites;* those of sulphurous acid, *sulphites;* etc., etc. You will notice that the last syllable of the name of the salt differs according to the name of the acid. If the name of the acid ends in *ic*, the name of the salt ends in *ate*. If the name of the acid ends in *ous*, the name of the salt ends in *ite*. To distinguish between the different salts of the same acid, the name of the metal contained in it is put before the general name of the salt.

Thus, the potassium salt of nitric acid is called potassium nitrate, the sodium salt is called sodium nitrate; the calcium salt of sulphuric acid is called calcium sulphate; the magnesium salt of nitrous acid is magnesium nitrite; the calcium salt of hypochlorous acid is calcium hypochlorite, etc., etc.

[Give the name and formula of the potassium salt of perchloric acid.—Give the name and formula of the sodium salt of hypochlorous acid.—Give the name and formula of the sodium salt of nitric acid.]

Salts of Hydrochloric Acid.—If the salts of hydrochloric acid were named in accordance with the principle just explained, they would be called *hydrochlorates*. But these salts are identical with the products formed by direct combination of the metals with chlorine. Thus hydrochloric acid and zinc act as represented in the equation

$$Zn + 2HCl = ZnCl_2 + 2H;$$
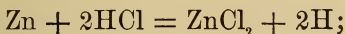
while zinc and chlorine act thus:

$$Zn + 2Cl = ZnCl_2.$$
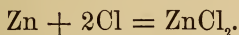
In each case the same product, $ZnCl_2$, is formed. But these compounds of metals with chlorine are called *chlorides*, as has already been explained. Hence the name hydrochlorates is unnecessary.

Acid Properties and Oxygen.—The observation that oxygen is generally present in acids led at one time to the belief that it is a necessary part of these substances. Hence the name oxygen, which means the *acid-former*, was given to it. That oxygen is not essential to the existence of acid properties is shown in the case of hydrochloric

acid, and in a few other similar cases. It must be said, however, that the acid properties of substances are generally due to the presence of oxygen. Some substances with basic properties are converted into acids by causing them to combine with more oxygen.

CHAPTER XII.

CARBON.

Carbon Found in All Living Things.—Wood, meat, fruits, and most other products of vegetable or animal life, when heated to a sufficiently high temperature *blacken*, and afterwards, if they are heated in the air, they burn up, as we say. This blackening is due to the fact that the substances all contain carbon. When they are heated without access of air the other elements are first driven off in various forms of combination, while a part of the carbon remains behind. If they are heated in the air, the carbon finally combines with oxygen to form a colorless gas—it burns up.

Destructive Distillation.—The process of heating substances in closed vesels and collecting the prducts formed is called *destructive distillation*. Among the most interesting examples of destructive distillation are those of coal and of wood. Coal is heated, as already stated under Ammonia, for the purpose of making illuminating-gas. Wood is heated for the purpose of making charcoal. Many interesting and important substances are obtained in these processes. Some of them will be taken up farther on.

Occurrence of Carbon.—From what has already been said you will see that the principal form in which carbon occurs in nature is in combination with other elements. It occurs not only in all living things, but in their fossil remains, as in coal. *Coal-oil* or *petroleum* consists of a large number of compounds that contain only carbon and hydrogen. Most products of plant-life contain the elements carbon, hydrogen, and oxygen. Among the more common of these products are sugar, starch, cellulose, etc. Most products of animal life contain carbon, hydrogen, oxygen, and nitrogen. Among them may be mentioned albumin, fibrin, casein, etc. Carbon occurs in the atmosphere in the form of carbon dioxide or carbonic acid. It also occurs in the form of salts of carbonic acid, the carbonates, which are widely distributed, forming some large mountain-ranges. Limestone, marble, and chalk are calcium carbonate.

Forms of the Element Carbon.—Uncombined, the element occurs pure in two very different forms in nature: (1) As *diamond;* and (2) as *graphite* or *plumbago*.

Diamond.—The celebrated diamond-beds are in the East Indies, Borneo, Sumatra, Brazil, and South Africa. When found, diamonds are covered with an opaque layer, which must be removed before the beautiful properties appear. Diamond is the hardest substance known. Heated to a high temperature in oxygen, it burns up, forming only carbon dioxide.

Small diamonds have been made by dissolving charcoal in molten iron in a crucible in an electric furnace, and then plunging the crucible into water. Under these conditions the outside of the molten mass is quickly solidi-

fied while the inner portions are still liquid and under strong pressure. Small diamonds have been found in meteorites.

Graphite.—Graphite, or plumbago, is found in nature in large quantities. It can be prepared artificially by dissolving charcoal in molten iron. From this solution it is deposited as graphite on cooling. It has a grayish-black color and a metallic lustre. It is quite soft, leaving a leaden-gray mark on paper when drawn across it, and is hence used in the manufacture of so-called *lead* pencils. It is also used as a lubricant for bicycle chains, etc. It is sometimes called *black lead*. Heated to a very high temperature in the air, or in oxygen, it burns up, forming only carbon dioxide.

Amorphous Carbon.—All forms of carbon which are not diamond, nor graphite, are included under the name *amorphous carbon*. This name means simply that it is not crystallized.

How Charcoal is Made.—Charcoal is that form of carbon which is made by the *charring* process. This consists in heating without a free supply of air. The substance almost exclusively used in the manufacture of charcoal is wood. Wood consists of a large number of substances, nearly all of which are made up of the three elements carbon, hydrogen, and oxygen. When wood is burned in the air the products are carbon dioxide and water. If the air is prevented from coming freely in contact with the wood, the hydrogen is given off partly as water and partly in the form of volatile compounds containing carbon and oxygen. The carbon, however, is mainly left behind as charcoal, as there is not enough oxygen present to burn it.

A Charcoal-kiln.—This consists essentially of a pile of wood so arranged as to leave spaces between the pieces. The pile is then covered either with brick-work or some rough material through which the air will not pass easily, as, for example, a mixture of powdered charcoal, turf, and earth. Small openings are left in the covering. A part of the wood burns and furnishes heat enough to char the rest. After a time the holes through which the air gains access to the wood are closed up, and the process stops. Charcoal, which is impure amorphous carbon, is left behind.

Properties of Charcoal.—Ordinary charcoal is a black, comparatively soft substance. It burns in the air, though not easily, unless the gases which are formed are constantly removed and fresh air is supplied, as by blowing with a bellows. It burns readily in oxygen, as we have seen (Experiment 24). The product of the combustion in oxygen and in air, when there is no lack of oxygen, is carbon dioxide, CO_2. In the air when the draught is bad, another compound of carbon and oxygen, carbon monoxide, CO, is formed.

Coke.—This is a form of amorphous carbon which is made by heating ordinary gas-coal without access of air, as is done on a large scale in the manufacture of illuminating-gas. Coke bears to coal about the same relation that charcoal bears to wood.

Lamp-black is a very finely divided form of carbon which is deposited on cool objects placed in the flames of burning oils. Most flames used for illuminating purposes give a black deposit of soot on objects placed in them. This soot is largely made up of fine particles of carbon. It is used in the manufacture of printer's ink. Carbon is

acted upon directly by very few substances, and is insoluble, so that it is impossible to destroy the color of printer's ink without destroying the material upon which it is impressed.

Bone-black, or Animal Charcoal, is a form of amorphous carbon which is made by charring bones and other animal substances. Unless it is treated with an acid it contains the incombustible substances which form a part of bones.

Charcoal-filters. — Bone-black and wood-charcoal are very porous and have the power to absorb gases. When placed in air containing bad-smelling gases, these are absorbed and the air thus purified. When water which contains disagreeable substances is treated with charcoal, these are wholly or partly absorbed and the water improved. Charcoal-filters are therefore extensively used. A charcoal-filter to be of value should be of good size, and from time to time the charcoal should be taken out and renewed. The small filters which are screwed into faucets are of little value, as the charcoal soon becomes charged with objectionable matter and thus becomes a source of contamination.

Bone-black Filters.—Some coloring matters are removed from liquids by passing the liquids through bone-black filters. On the large scale, this fact is taken advantage of in the refining of sugar. The solution of sugar first obtained from the cane or beet is strongly colored; and if it were evaporated, the sugar deposited from it would be dark-colored. If, however, the solution be first passed through bone-black filters, the color is removed.

EXPERIMENT 68.—Make a filter of bone-black by fitting a paper filter into a funnel 12 to 15 mm. (5 to 6 inches) in diameter at its

mouth. Half fill this with bone-black. Pour a dilute solution of indigo * through the filter. If the conditions are right the solution will pass through colorless.—Do the same thing with ink much diluted with water.—If the color is not completely removed by one filtering, filter the solutions again.—The color may also be removed from solutions by putting some bone-black into them and boiling for a time. Try this with half a litre each of the ink and indigo solutions used in the first part of the experiment. Use about 4 to 5 grams bone-black in each case. Shake the solutions frequently while heating.

Charring Prevents Decay.—Charcoal does not decay in the air or under water nearly as readily as wood. That is another way of stating the chemical fact that the substances of which wood is made up are more susceptible to ordinary chemical action than charcoal is. We have one illustration of this in the relative ease with which charcoal and wood burn in the air. Piles which are driven below the surface of water are charred to protect them from the action of those substances which cause decay.

Coal.—Under this head are included a great many kinds of impure amorphous carbon which occur ready-formed in nature. Ordinarily coals are divided into *hard* and *soft coals*, or *anthracite* and *bituminous coals*. Then there are substances more closely related to wood, and therefore called *lignite*, and those which represent a very early stage in the process of coal-formation, viz., *peat*.

Formation of Coal.—A close examination of all these varieties has shown that they have been formed by the gradual decomposition of vegetable material where there was not free access of air. The process has been going on for ages. Sometimes the substances have been subjected

* Prepared by treating powdered indigo for some time with warm concentrated sulphuric acid and diluting with much water.

to great pressure, as can be seen from the position in which they occur in the earth.

Destructive Distillation of Coal.—All forms of coal contain other substances besides carbon. The soft coals are particularly rich in other substances. When heated they give off a mixture of gases and vapors of volatile liquids. The gases are, for the most part, useful for illuminating purposes. The liquids form a black, tarry mass known as *coal-tar*, from which are obtained many valuable compounds of carbon. The gases are passed through water for the purpose of removing certain impurities. This water absorbs ammonia and forms the *ammoniacal liquor* of the gas-works.

Diamond, Graphite, and Charcoal Different Forms of the Element Carbon.—An element, as you have learned, is a form of matter which cannot be decomposed into simpler substances by any means now known to chemists. From hydrogen we can get nothing but hydrogen, except by bringing it together with some other element; from nitrogen we can get nothing but nitrogen, etc. In the case of carbon, however, it is possible for the element to appear in three forms, which differ markedly from one another. That they are the same substance, chemically speaking, can be proved by a comparatively simple experiment. If we were to burn the same weight of diamond, of graphite, and of charcoal, and collect and weigh the carbon dioxide formed in each case, we should find that the weight of carbon dioxide formed is the same in each case. Further, knowing the composition of carbon dioxide, we know how much carbon is contained in a given weight of the gas. Calculating the quantity of carbon

contained in the carbon dioxide obtained in burning a
piece of diamond, we should find that it is exactly equal
to the weight of the diamond; and the same thing is true
of graphite and charcoal.

PROBLEM.—How much carbon dioxide, CO_2, should be ob-
tained by burning 0.5 gram diamond? The combining weight of
carbon is 12.

Common Properties of the Different Forms of Carbon.—
Notwithstanding the marked differences in their appear-
ance the different forms of carbon have some properties
in common. They are insoluble in all ordinary liquids.*
They are tasteless, inodorous, and infusible. When
heated without access of air, they remain unchanged
unless the temperature is very high.

Allotropy.—That one and the same substance can
appear in markedly different forms under different condi-
tions is seen in the case of water. Hail and snow would
hardly be suspected of being the same substance by one
not quite familiar with them. The difference in this
case, as in that of carbon, is believed to be due to the way
in which the small particles of which the substances are
made up are arranged. If we had a number of small
pieces of wood all of the same size and shape, say cubes,
and should carefully arrange them in some regular way,
we might easily make a comparatively compact mass of
them, and the mass would have a regular form. We
might, further, arrange them in some second way with
regularity. And we might simply throw the pieces
together in a jumble. These three kinds of arrangement
would represent, in a rough way, the difference between

* They are all soluble in molten iron.

the three forms of carbon. Each pile would be made of wood, but in outward appearance they would differ from one another. In a similar way oxygen and ozone differ from each other. The power which some elements have of existing in different conditions is called *allotropy*.

Chemical Conduct of Carbon.—At ordinary temperatures carbon is an inactive element. If it is left in contact with any one of the elements thus far treated of—viz., hydrogen, oxygen, chlorine, and nitrogen—no change takes place. At higher temperatures, however, it readily combines with other elements, especially oxygen. It combines with oxygen either directly, as when it burns in the air or oxygen; or it abstracts oxygen from some of the oxides.

Direct Combination of Carbon with Oxygen.—This has already been illustrated in Experiment 24, and is familiar to every one in charcoal-fires. That carbon dioxide is the product formed may be shown by passing the gas into lime-water, when insoluble calcium carbonate will be thrown down. Lime-water is made by adding water to some quicklime. The lime is slaked and some of the product, calcium hydroxide, $Ca(OH)_2$, dissolves in the water. The excess of the calcium hydroxide settles and leaves a clear solution above if the vessel is allowed to stand quietly.

EXPERIMENT 69.—Put a small piece of charcoal in a piece of hard-glass tube. Pass oxygen through the tube, at the same time heating it. Pass the gases into clear lime-water. Arrange the apparatus as shown in Fig. 30. *A* is a bottle containing oxygen; *B* is the hard-glass tube containing the charcoal; *C* is the cylinder with clear lime-water. The reason why lime-water is used is that an insoluble compound is formed, and this can be

seen, and it can be separated from the liquid and examined. The reaction which takes place is represented thus :

$$CaO_2H_2 \quad + \quad CO_2 \quad = \quad CaCO_3 \quad + \quad H_2O.$$
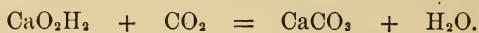
Lime   and carbon dioxide give calcium carbonate (insoluble) and water.
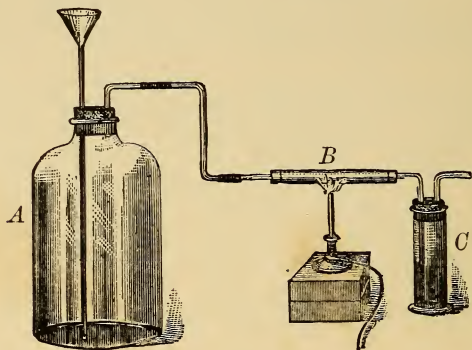
FIG. 30.

No other common gas acts in this way with lime-water. Hence, when, under ordinary circumstances, a gas is passed into lime-water and an insoluble substance is formed, we may conclude that the gas is carbon dioxide.

Carbon Abstracts Oxygen from Oxides.—This may be illustrated by the following experiments :

EXPERIMENT 70.—Mix together 2 or 3 grams powdered copper oxide, CuO, and an equal bulk of powdered charcoal ; heat in a hard-glass tube to which is fitted an outlet tube, as shown in Fig. 31. Pass the gas which is given off into clear lime-water contained in a test-tube.—Is it carbon dioxide ? What evidence have you that oxygen has been extracted from the copper oxide ? What is the appearance of the substance left in the tube ? Does it suggest the metal copper ? Treat a little with strong nitric acid. What should take place if the substance is

FIG. 31.

metallic copper ? (See Experiment 56.) What does take place ?
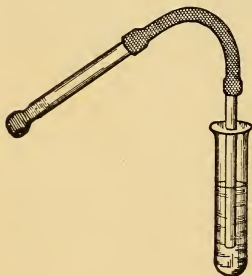
The reaction between the charcoal and the copper oxide is represented thus:

$$2CuO + C = 2Cu + CO_2.$$
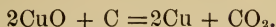
EXPERIMENT 71.—Perform a similar experiment with a little *white arsenic* in a small glass tube closed at one end. Take about equal parts of charcoal and arsenic. White arsenic is a compound of the elements arsenic and oxygen, As_2O_3. The reaction which takes place when it is heated with charcoal is represented thus:

$$2As_2O_3 + 3C = 4As + 3CO_2.$$
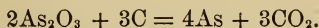
The element arsenic is volatile, and is hence driven out of the bottom of the tube and deposited on the sides of the tube above the mixture in the form of a mirror with a metallic lustre.

Use of Carbon (Charcoal) as a Reducing Agent.—As has already been explained, the abstraction of oxygen from a compound is called *reduction.* Hence carbon is called a reducing agent. It is extensively used for the purpose of extracting metals from their ores, which are the forms in which they occur in nature. Thus, iron does not occur in nature as iron, but in combination with other elements, particularly oxygen. In order to get the metal the ore must be reduced, or, in other words, the oxygen must be extracted. This is always accomplished by heating it with some form of carbon, either charcoal or coke.

[What other element which you have already studied acts as a reducing agent? Give an example of its reducing power.]

CHAPTER XIII.

COMPOUNDS OF CARBON WITH HYDROGEN, OXYGEN, AND WITH NITROGEN.

Compounds of Carbon and Hydrogen.—In the laboratory it is not a simple matter to effect combination between carbon and hydrogen except in a few simple cases. In nature processes are in operation that give rise to the formation of a large number of compounds containing these elements; and, further, in the manufacture of illuminating-gas from coal the conditions are such as to cause the combination of carbon and hydrogen, several interesting compounds being thus formed. There are no other two elements that combine with each other in as many different proportions as carbon and hydrogen. The compounds thus formed are known as *hydrocarbons*. The number of hydrocarbons known is very great, being somewhere near two hundred. Fortunately, investigation has shown that quite simple relations exist between these compounds; and hence, though the number is large, the study is not as difficult as might be expected.

Petroleum, which is a mixture of various hydrocarbons, gaseous, liquid, and solid, is found in many places in the earth in large quantity, particularly in Pennsylvania, West Virginia, Ohio, California, Texas, and the Caucasus.

When it is brought into the air, the pressure being removed, the gases are given off. There are several gaseous hydrocarbons given off, and a large number of liquids left behind.

Refining Petroleum.—The vapors from petroleum when mixed with air are explosive, and the thicker liquids clog the lamps and wicks. Therefore these must be removed before the oil is fit for household use. This is done by (1) distilling, (2) washing with sulphuric acid, (3) washing with alkali, and (4) washing with water. The product thus prepared is called *kerosene.*

In refining petroleum a number of products are obtained which cannot be used in lamps. Those which are lighter than kerosene, that is to say those which boil at a lower temperature, are known as *gasoline, naphtha, benzine*, etc. From the heavier portions, or those which boil at higher temperatures than kerosene, *lubricating oils* and *paraffin* are made. Each of these substances is a mixture of several hydrocarbons.

Hydrocarbons contained in Petroleum.—The simplest hydrocarbon contained in petroleum is methane, or marsh-gas, CH_4; the next has the composition C_2H_6, the next C_3H_8, etc. It will be seen that these compounds bear a simple relation to one another, as far as composition is concerned. They are the first members of a series the names and symbols of the first eight members of which are given below:

CH_4, Methane, or Marsh-gas;
C_2H_6, Ethane;
C_3H_8, Propane;
C_4H_{10}, Butane;

C_5H_{12}, Pentane;
C_6H_{14}, Hexane;
C_7H_{16}, Heptane;
C_8H_{18}, Octane.

Homology.—The first member of the series differs from the second by CH_2; there is also this same difference, in general, between any two consecutive members of the series. This relation is known as *homology*, and such a series as an *homologous series*. Carbon is distinguished from all other elements by its power to form homologous series.

The Ethylene Series of Hydrocarbons.—Besides the series above mentioned which is known as the *marsh-gas series*, there are other homologous series of hydrocarbons. There is one beginning with ethylene, C_2H_4, examples of which are

Ethylene, C_2H_4;
Propylene, C_3H_6;
Butylene, C_4H_8.

The Acetylene Series.—There is a series beginning with acetylene, examples of which are

Acetylene, C_2H_2;
Allylene, C_3H_4.

The Benzene Series.—Another series begins with benzene, C_6H_6. Some of the members of this series are

Benzene, C_6H_6;
Toluene, C_7H_8;
Xylene, C_8H_{10}.

Marsh-gas, Methane, Fire-damp, CH_4.—Marsh-gas is found in nature in petroleum, and is given off when the

oil is taken out of the earth. It also occurs in "natural gas." It is formed, as the name implies, in marshes, as the product of a reducing process. Vegetable matter is composed of carbon, hydrogen, and oxygen. When it undergoes decomposition in the air in a free supply of oxygen, the final products are carbon dioxide and water. When the decomposition takes place without access of oxygen, as under water, marsh-gas, which is a reduction product, is formed. It bears to carbon much the same relation that ammonia bears to nitrogen.

Occurrence of Marsh-gas in Coal-mines.—Marsh-gas is met with in coal-mines, and is known to the miners as *fire-damp*. Mixed with air it is one of the causes of the terrible explosions which occur in coal-mines.

Preparation of Marsh-gas.—Marsh-gas is most readily prepared in the laboratory by heating sodium acetate with caustic potash and quicklime.

EXPERIMENT 72.—Mix 5 grams dry sodium acetate, 5 grams potassium hydroxide, and 7½ grams quicklime. Heat in a retort. Collect over water as in making nitrous oxide. Does the gas burn? Does it give light in burning?

Properties of Marsh-gas. — Marsh-gas is a colorless, transparent, tasteless, inodorous gas slightly soluble in water. It burns, forming carbon dioxide and water. When mixed with air, the mixture explodes if a flame or spark comes in contact with it.

Ethylene, Olefiant Gas, C_2H_4.—This hydrocarbon is formed by heating a mixture of ordinary alcohol and concentrated sulphuric acid. It is a colorless gas which can be condensed to a liquid. It burns with a luminous flame.

Acetylene, C_2H_2.—Acetylene is formed when a current

of hydrogen is passed between carbon poles which are incandescent in consequence of the passage of a powerful electric current. In this case carbon and hydrogen combine directly. It is formed also when the flame of an ordinary laboratory burner (Bunsen burner) "strikes back," or burns at the base without a free supply of air. It is most easily formed by treating *calcium carbide* (which see) with water when the reaction below represented takes place:

$$CaC_2 \quad + \quad 2H_2O \quad = \quad C_2H_2 \quad + \quad Ca(OH)_2.$$

Calcium carbide   and   water   give   acety-lene   and   calcium hydroxide.
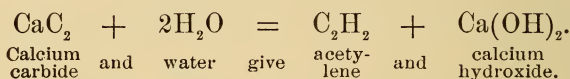
EXPERIMENT 73.—Arrange an apparatus as shown in Fig. 32.
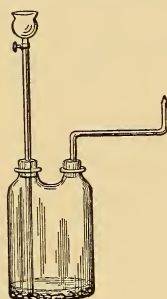
This is a small Woulff's flask into one neck of which is fitted a funnel-tube furnished with a stop-cock, while into the other is fitted a bent glass tube ending in a small opening, or better, an acetylene burner. Put a few pieces of granulated calcium carbide in the dry flask. Now close it and admit water slowly through the funnel-tube. After the gas has escaped for some time light it.

FIG. 32.

Its odor is unpleasant. It burns with a luminous, smoky flame. The gas is now much used for illuminating purposes. Rather unsatisfactory small bicycle lamps, in which the gas is generated from calcium carbide, have been devised.

The Manufacture of Illuminating-gas.—"Coal-gas," as the name implies, is made from coal. For this purpose, as has been stated, the coal is heated in closed vessels. The products formed are first passed through a series of tubes that are kept cool. In these a thick

black liquid, known as *coal tar*, collects. Then the gaseous products are passed through water which takes up ammonia. The gases which remain are treated with two or three other substances to remove impurities, and are then collected in large vessels called gasometers. One ton of gas-coal yields an average of 10,000 cubic feet of gas.

Coal Tar.—Coal tar contains a very large number of compounds, some of which are obtained from it by distillation. The first products that pass over contain the hydrocarbons of the benzene series, of which benzene itself is the principal one.

Carbon Dioxide, CO_2.—The principal compound of carbon and oxygen is carbon dioxide, CO_2, commonly called *carbonic acid gas*.

Occurrence of Carbon Dioxide.—Under the head of The Atmosphere it was stated that this gas is always present in the air. It issues from the earth in many places, particularly in the neighborhood of volcanoes. Many mineral waters contain it in considerable quantity, as the waters of Pyrmont, Selters, and the Geyser Spring at Saratoga. In small quantity it is present in all natural waters. In combination with bases it occurs in enormous quantities, particularly in the form of calcium carbonate, $CaCO_3$, varieties of which are ordinary limestone, chalk, marble, and calc-spar.

Natural Formation of Carbon Dioxide.—Carbon dioxide is constantly formed in a number of natural processes. Thus, all animals in breathing give off carbon dioxide.

EXPERIMENT 74.—Blow through some lime-water by means of

an apparatus arranged as shown in Fig. 33. What evidence have you that your lungs give off carbon dioxide?

It has already been shown that carbon dioxide is formed in the combustion of charcoal and wood. In a similar way it can be shown that the gas is formed whenever any of our ordinary combustible materials are burned. From our fires as from our lungs, and from the lungs of all animals, then, carbon dioxide is constantly given off. Further, the natural processes of decay of both vegetable and animal matter tend to convert the carbon of this matter into carbon dioxide, and this is then spread through the air. The process of alcoholic fermentation, and some other like processes, also give rise to the formation of carbon dioxide. In all fruit-juices there is contained sugar. When the fruits ripen, fall off, and decay, the sugar is changed to alcohol and carbon dioxide.

Preparation of Carbon Dioxide.—The easiest way to get carbon dioxide is to add an acid to a carbonate. Whenever any acid is added to any carbonate there is an evolution of gas.

Experiment 75.—In different test-tubes containing a little sodium carbonate add dilute hydrochloric, sulphuric, nitric, and acetic acids.—What takes place? Is a gas given off? Pass it through lime-water. Is it carbon dioxide?—Perform the same experiment with small pieces of marble. What gas is given off?

To prepare carbon dioxide in the laboratory, calcium carbonate in the form of marble, or limestone, and hydro-

FIG. 33.

chloric acid are commonly used. The reaction is represented thus:

$$CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O.$$
Calcium
carbonate.
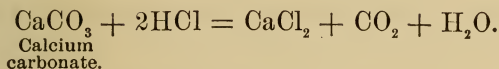
[What is the substance $CaCl_2$?]

EXPERIMENT 76.—Arrange an apparatus as shown in Fig. 34. In the flask put some pieces of marble, and pour ordinary hydrochloric acid on it. Collect the gas by displacement of air, placing the vessel with the mouth upward. Fill several cylinders or bottles with the gas.—Into one introduce a lighted candle, and afterwards a burning stick. What takes place? With another proceed as if pouring water from it. Pour the invisible gas upon the flame of a burning candle. Pour some of the gas from one vessel to another, and show that it has been transferred. Balance a beaker on a good-sized scales, and pour carbon dioxide into it. If the balance is at all sensitive, the pan in which the beaker is placed will go down.
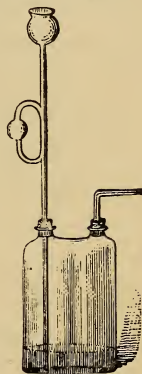
FIG. 34.

Properties of Carbon Dioxide.—From the observations you have just made you have learned that carbon dioxide is a colorless gas at the ordinary temperature; that it is incombustible and does not support combustion; and that it is heavier than the air. When subjected to a low temperature and high pressure it is converted into a liquid, and this can further be changed to a solid. It has a slightly acid taste and smell.

Why Carbon Dioxide does not Burn.—It does not burn for the same reason that water does not; because in the form of the dioxide the carbon already holds in combination all the oxygen it has the power to combine with. Before it can burn again the carbon dioxide must first be decomposed.

Carbon can do Chemical Work.—Carbon has the power to combine with oxygen, and in so doing a definite quantity of heat is given off. A pound of carbon represents a definite quantity of chemical energy, which we can get, first, in the form of heat, and then convert into other forms, as electricity, motion, etc. After the pound of carbon has been burned, the product no longer represents the energy the carbon did. Similarly, a body of water elevated ten or fifteen feet represents a certain quantity of energy which can be obtained by allowing the water to fall upon the paddles of a water-wheel connected with the machinery of a mill. After the water has fallen, however, it no longer has the power to do work, or it has no energy. In order that it may again do work it must again be lifted up.

Soda-water.—Carbon dioxide dissolves in water, one volume of water dissolving about its own volume of the gas at the ordinary temperature. When the pressure is increased the water dissolves more gas; and when the pressure is removed the gas again escapes. The so-called " soda-water " is water charged with carbon dioxide under pressure. The escape of the gas, when the water is drawn, is familiar to every one. The carbon dioxide used in charging the water was formerly made from a sodium salt of carbonic acid known as " bicarbonate of soda."

Breathing.—It has been stated that carbon dioxide is given off from the lungs as it is from a fire, and the fact was shown by means of a simple experiment. It is a waste product of the processes going on in the animal body. Just as it cannot support combustion, so animals cannot breathe in it. It is not poisonous any more than

water is; but it cannot supply the oxygen which is needed for breathing purposes. In it animals die of suffocation, as they do in water. Any considerable increase in the quantity of carbon dioxide in the air above that which is generally present is objectionable, because it decreases the proportion of oxygen in the air which is breathed. If pure carbon dioxide is introduced into the air it has been shown that as much as 5 per cent may be present without causing injury to those who breathe it.

Air in Badly Ventilated Rooms.—In a badly ventilated room in which a number of people are collected and lights are burning, it is well known that in a short time the air becomes foul, and bad effects, such as headache, drowsiness, etc., are felt by those in the room. These effects are caused, not by the carbon dioxide, but by other waste products which are given off from the lungs in the process of breathing. The gases given off from the lungs consist of nitrogen, oxygen, carbon dioxide, and water-vapor. Besides these, however, there are many substances in a fine state of division which contain carbon, and are in a state of decomposition. These are poisonous, and appear to be the chief cause of the bad effects experienced in breathing air which has become contaminated by the exhalations from the lungs.

Carbon Dioxide in Old Wells.—As carbon dioxide is formed in the earth wherever an acid solution comes in contact with a carbonate, the gas is frequently given off from fissures in the earth. As acid solutions are formed by the action of the air and moisture upon various mineral substances found in and upon the earth, the gas is sometimes found in old wells which have not

been in use for some time, and deaths have been caused by descending these wells for the purpose of repairing them. It is a good plan to let down a lighted candle into such a well before venturing to go down. If the candle continues to burn, the air can be breathed without danger.

Choke-damp.—Carbon dioxide is also met with in mines, and is called *choke-damp* by the miners. The miners know that after an explosion caused by fire-damp there is danger of death from choke-damp. The reason is this. When fire-damp, or marsh-gas, explodes with air the carbon is converted into choke-damp, or carbon dioxide, and the hydrogen into water.

Carbon Dioxide the Food of Plants.—Plants live largely on the carbon dioxide contained in the air. They have the power, with the aid of the sun's light, to decompose the gas, and they then build up the complex compounds of carbon which form their tissues, using for this purpose the carbon of the carbon dioxide which they have decomposed and returning the oxygen at least partly to the air.

Plants the Food of Animals.—Animals eat either the products of plant-life or other animals which get their food from the vegetable kingdom. The food of animals comes, then, either directly or indirectly from plants. The food taken into the animal body is partly changed into other substances which form the structure of the animal; and partly it is oxidized, thus serving to keep the temperature of the body up to the necessary point. That part of the food which suffers oxidation in the body acts the same as fuel in a stove. It is burned up, producing heat, the carbon being converted into carbon dioxide which is given off from the lungs.

Carbon Dioxide Returns to the Air.—From fires and living things carbon dioxide is returned to the air, where it again serves as food for plants. When the life-process stops in the animal or plant, decomposition begins; and the final result of this, under ordinary circumstances, is the conversion of the carbon into the dioxide.

No Life Without the Sun. — Every living thing is dependent upon the decomposition of carbon dioxide by plants, and this decomposition cannot be effected without the aid of the sun. If the sun should stop shining, soon all life would cease. As the heat of the sun acting upon the great bodies of water and on the air gives rise to the movements of water which are essential to the existence of the world as it is, so the action of the sun's rays on carbon dioxide, in the presence of the delicate and inexplicable mechanism of the leaf of the plant, gives rise to those changes in the forms of combination of the element carbon which accompany the wonderful process of life.

Carbonic Acid.—A solution of carbonic acid in water has a slightly acid reaction. The solution will act upon basic solutions and form salts. The composition of the sodium salt formed in this way is Na_2CO_3; that of the potassium salt K_2CO_3, etc. These salts are plainly derived from an acid, H_2CO_3, which is carbonic acid. It is probable that the acid is contained in the solution of carbon dioxide in water. It is, however, so unstable that it breaks up into carbon dioxide and water:

$$H_2CO_3 = CO_2 + H_2O.$$

The Carbonates.—When carbon dioxide acts upon a base it forms a salt. Thus, when potassium hydroxide or

calcium hydroxide is used, the action which takes place is represented thus:

$$2KOH + CO_2 = K_2CO_3 + H_2O;$$
$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$
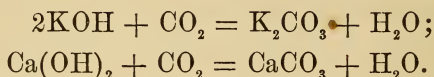
EXPERIMENT 77.—Pass carbon dioxide into a solution of caustic potash until it will absorb no more. Add acid to some of the solution thus obtained, and convince yourself that the gas given off is carbon dioxide. Write the equations expressing the reactions which take place on passing the carbon dioxide into the caustic-potash solution, and on adding an acid to the solution. What evidence have you that the gas given off is carbon dioxide?

EXPERIMENT 78.—Pass carbon dioxide into 50 to 100 c.c. clear lime-water. Filter off the white insoluble substance. Try the action of a little acid on it. What evidence have you that it is calcium carbonate? How could you easily distinguish between lime-water and a solution of caustic potash?

Calcium Carbonate Dissolves in Water containing Carbon Dioxide.—If you continue to pass carbon dioxide into lime-water after the calcium carbonate has been formed, the carbonate dissolves, and the solution finally becomes clear. If this solution is heated, the carbon dioxide is driven off and the calcium carbonate is again thrown down.

EXPERIMENT 79.—Pass carbon dioxide first through a little water to wash it, and then into 50 to 100 c.c. clear lime-water. After the solution has become clear, heat it.

Hard Water.—Natural waters that flow over limestone take up more or less calcium carbonate by virtue of the carbon dioxide which they absorb from the air. Such waters, which are called "hard waters," are in the condition of the solution of calcium carbonate above referred to. When heated, the calcium carbonate is deposited. This is frequently noticed in the deposits in boilers and other vessels in which water is boiled. This kind of

hardness is called "temporary hardness," to distinguish it from "permanent hardness" which is not affected by boiling.

Carbon Monoxide, CO.—This compound is formed when a substance containing carbon is burned in an insufficient supply of air,—as, for example, when the draught in a furnace is not strong enough to remove the products of combustion and supply fresh air. It can also be made by extracting oxygen from carbon dioxide. It is only necessary to pass the dioxide over heated carbon, when the reaction which is represented in the following equation takes place:

$$CO_2 + C = 2CO.$$
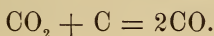
Formation of Carbon Monoxide in Coal-fires. — The formation of carbon monoxide can be well observed in a hard-coal fire in an open grate. The air has free access to the coal, and at the surface complete oxidation takes place. But that part of the carbon dioxide which is formed at the lower part of the grate is drawn up through the heated coal and is partly reduced to carbon monoxide. When the monoxide escapes from the upper part of the grate it again combines with oxygen, or burns, causing the characteristic blue flame always noticed above a mass of burning hard coal.

Carbon Monoxide contained in Water-gas.—Water-gas, as has been stated under Hydrogen, is made by passing water-vapor over highly heated coal, when this reaction takes place:

$$C + H_2O = CO + 2H.$$

The gas obtained is therefore a mixture of carbon monoxide and hydrogen. Before use it is enriched by the

addition of hydrocarbons from petroleum. As carbon monoxide is poisonous, laws have been passed in some States prohibiting the use of water-gas.

Preparation of Carbon Monoxide.—Carbon monoxide is most easily made by heating oxalic acid, $C_2H_2O_4$ with sulphuric acid. The change which takes place is represented thus:

$$C_2H_2O_4 = CO_2 + CO + H_2O.$$
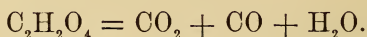
Sulphuric acid, as will be shown later, has a marked power of combining with water. In this case it takes the elements of water from the oxalic acid and that which is left, C_2O_3, breaks down into carbon monoxide and carbon dioxide.

In order to separate the two gases the mixture is passed through a solution of caustic soda, which takes up the carbon dioxide [forming what?] and allows the monoxide to pass.

Experiment 80.—Put 10 grams crystallized oxalic acid and 50–60 grams concentrated sulphuric acid in an appropriate-sized flask. Connect with two Woulff's flasks containing a solution of caustic soda. Heat the contents of the flask gently. Collect some of the gas over water. Set fire to the same, and notice the characteristic blue flame.

Properties of Carbon Monoxide.—It is a colorless, tasteless, inodorous gas, insoluble in water. It burns with a pale blue flame, forming carbon dioxide. *It is exceedingly poisonous.* Hence it is very important that it should not be allowed to escape into rooms occupied by human beings.

Danger of Coal-stoves.—We sometimes hear of deaths caused by the gases from coal-stoves. The most dangerous gas given off from coal-stoves is probably carbon mon-

oxide. A pan of smouldering charcoal gives off this gas, and the poisonous character of the gas is well known.

Carbon Monoxide a Reducing Agent.—At high temperatures carbon monoxide combines readily with oxygen and it is hence a good reducing agent. In the reduction of iron from its ores the carbon monoxide formed in the blast-furnace plays an important part.

EXPERIMENT 81.—Pass carbon monoxide over some heated copper oxide contained in a hard glass tube. Is the oxide reduced ? How do you know ? Is carbon dioxide formed ? What evidence have you ? Was the carbon monoxide free of carbon dioxide ? If not, what evidence have you that carbon dioxide is formed in this experiment ?

Illumination.—In all ordinary forms of illumination we are dependent upon flames for the light. Whether we use illuminating-gas, a lamp, or a candle, the light comes from a flame. In the first case, the gas is burned directly; in the case of the lamp, the oil is first drawn up the wick, then converted into a gas, and this burns; while, finally, in the case of the candle, the solid material of the candle is first melted, then drawn up the wick, converted into gas, and the gas burns, forming the flame. In each case we have, then, a burning gas, and this burning gas we call a flame.

When Burning Gases are Cooled Down they are Extinguished.—You have already learned that substances need to be raised to the kindling temperature, before they will burn. This statement is as true of gases as of other substances. When a current of hydrogen is allowed to escape into the air, or into oxygen, no action takes place unless it is heated up to the burning temperature, when it takes

fire and continues to burn.   If the gas is cooled below this
temperature, the flame is extinguished.

EXPERIMENT 82.—Light a Bunsen burner.   Bring down upon
the flame a piece of brass or iron-wire gauze.   There is no flame
above the gauze.   That the gas passes through unburned can be
shown by applying a light just above the outlet of the burner and
above the gauze.   The gas will take fire and burn.   By passing
through the thin wire gauze, then, the gas is cooled down below
its burning temperature.   Turn on a Bunsen burner.   Do not
light the gas.   Hold a piece of wire gauze about one and a half to
two inches above the outlet.   Apply a lighted match above the
gauze, when the gas will burn above the gauze, but not below it.

The Safety-lamp.—The facts illustrated in the   last
experiments are utilized in the miner's safety-lamp.   One
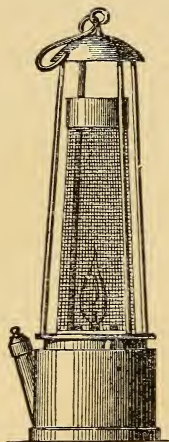
of the dangers which the miner has to
encounter is the occurrence of fire-damp,
or methane, CH_4, which with air forms an
explosive mixture.   The explosion can only
be brought about by contact of a flame
with the mixture.   In order to avoid the
contact, the flame of the safety-lamp is
surrounded by wire gauze, as shown in
Fig. 35.   When a lamp of this kind is
brought into a mixture of marsh-gas and
air, it, of course, passes through the wire
gauze and comes in contact with the flame.

FIG. 35.   A small explosion occurs inside the gauze,
but the flame inside cannot pass through.   Hence no
serious explosion takes place.   The flickering of the flame,
and the occurrence of small explosions inside the gauze,
furnish the miner with the information that he is in
danger.

Causes of the Luminosity of Flames.—There are several causes that cause flames to give light. One is the presence of solid substances in the flame. If a piece of platinum wire is put in a hydrogen flame which gives practically no light the flame becomes luminous. This fact has also been shown by introducing a piece of lime into the hot, non-luminous flame of the oxyhydrogen blow-pipe. A similar cause makes ordinary gas-flames luminous. There are always present in these flames particles of unburned carbon, as is shown by putting a solid substance into the flames, when a layer of soot, which consists mainly of finely divided carbon, is deposited on it. Again, the denser the gas the more light it gives. A candle on the top of a high mountain, as Mont Blanc, on which the experiment was performed, gives less light than the same candle does at the level of the sea. It has lately been shown that the formation and decomposition of acetylene (which see) in flames is an important factor in the luminosity of flames.

Cyanogen, C_2N_2.—Carbon does not combine with nitrogen under ordinary circumstances. If, however, they are brought together at very high temperatures in the presence of metals, they combine to form compounds known as *cyanides*. When refuse animal substances, such as blood, horns, claws, hair, wool, etc., are heated together with potassium carbonate and iron, a substance known as *potassium ferrocyanide*, or *yellow prussiate of potash*, $K_4FeC_6N_6 + 3H_2O$ is formed. When this is heated it decomposes, yielding potassium cyanide, KCN. From the potassium compound it is not difficult to make mercury

cyanide, $Hg(CN)_2$. By heating mercury cyanide it breaks down, yielding mercury and cyanogen gas:

$$Hg(CN)_2 = Hg + C_2N_2.$$
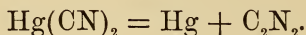
[What analogy is there between this reaction and that which takes place when mercury oxide is heated?]

Properties.—Cyanogen is a colorless gas, easily soluble in water and alcohol. It is extremely poisonous.

Hydrocyanic Acid, Prussic Acid, HCN. — This acid occurs in nature, in combination with other substances, in bitter almonds, the leaves of cherry, laurel, etc. It is prepared from potassium cyanide, just as hydrochloric acid is prepared from sodium chloride. The reaction is represented thus:

$$2KCN + H_2SO_4 = K_2SO_4 + 2HCN.$$
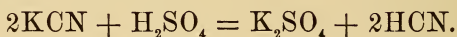
Properties.—Hydrocyanic acid is a volatile liquid. It has a very characteristic odor resembling that of bitter almonds. It is extremely poisonous. It dissolves in water in all proportions, and it is such a solution which is known as prussic acid.

Other Compounds of Carbon.—That part of Chemistry which has to do with the compounds of carbon is commonly called Organic Chemistry. It is more convenient to deal with this subject after the chemistry of the other common elements has been studied. The last part of this book will treat of some of the more common and better known compounds of carbon.

CHAPTER XIV.

ATOMIC THEORY — ATOMIC WEIGHTS — MOLECULAR
WEIGHTS — VALENCE — CLASSIFICATION OF THE
ELEMENTS.

The Laws of Chemical Action.—You have learned that
there are two laws always governing chemical combination.
These are the laws of definite and multiple proportions.
These laws are simply statements that sum up what has
been found to be true in all cases examined. They are
statements of facts discovered by actual experiment.

We may Know a Fact without Knowing its Cause.—It
is one thing to know a general fact, and quite another to
know the cause of the fact. We know that all bodies are
attracted by the earth, and that they fall when thrown
into the air. But we do not know why this is so. So,
too, though we know that substances combine according
to the laws of definite and multiple proportions, it does
not necessarily follow that we know why they combine
according to these laws.

Hypothesis and Theory.—When a law has been discov-
ered by careful study of the facts, the next thing to be
done is to *imagine a cause*. We try to imagine a condition
of things which, if it existed, would lead to the results
discovered. If we succeed in imagining such a condition

of things we suggest an *hypothesis.* If, now, we test this hypothesis in every way that suggests itself, and find that all facts discovered are in accordance with it, we then call it a *theory.* An hypothesis is a guess in regard to the cause of certain phenomena. A theory is an hypothesis which has been thoroughly tested, and which is applicable to a large number of related phenomena.*

The Atomic Theory.—The atomic theory was suggested to account for the laws of definite and multiple proportions. The theory is this:

That all kinds of matter are made up of indivisible particles called atoms; and that the atoms of the different elements have different weights.

Now if, when substances act upon one another, the action takes place between these atoms, and consists either in a union or separation of the atoms, then it is easy to understand why compounds are formed according to the law of definite and multiple proportions. If two elements whose atoms have weights which are to each other as 2 to 9 combine so that one atom of the one combines with one atom of the other, then the compound which is formed will contain the elements in the proportion of 2 parts by weight of the one to 9 parts by weight of the other element. If they combine so that one atom of the first element combines with two atoms of the other, then the

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* Hypotheses and theories are of great value to science, if founded upon a thorough knowledge of the facts to which they relate. They become dangerous when used by those who are not familiar with the facts. The student who has not received a thorough scientific training should remember that theories and hypotheses, to be of value, must be suggested, not by a superficial but by a thorough knowledge of the facts.

resulting compound will contain the elements in the proportion of 2 parts by weight of the one to 18 parts by weight of the other element.

Atomic Weights.—The weights of the elements which have thus far been referred to as *combining weights* are, in accordance with the atomic theory, the relative weights of the atoms, or the *atomic weights*. The symbols of the elements represent atoms of the elements. Thus, H represents an atom of hydrogen, O an atom of oxygen, etc. As hydrogen enters into combination in smaller proportion than any other element, its combining weight or atomic weight is taken as the unit. When we say that the atomic weight of oxygen is 16, we mean that the atom of oxygen is 16 times heavier than that of hydrogen.

Molecules.—As the symbols of the elements represent atoms, so the symbols of compounds represent combinations of atoms. The symbol of hydrochloric acid, HCl represents, according to the theory, the smallest particle of this substance that can exist. It is made up of an atom of hydrogen and an atom of chlorine, which are combined chemically. The symbols HNO_3, H_2O, NH_3 are intended to represent the smallest particles of the compounds that can exist. The smallest particle of nitric acid consists of 1 atom of nitrogen, 1 atom of hydrogen, and 3 atoms of oxygen. These smallest particles of compounds are called *molecules*. The molecules are made up of atoms. The weight of a molecule is equal to the sum of the weights of the atoms of which it is composed.

Avogadro's Hypothesis.—A careful study of the conduct of gases led to the conclusion that *equal volumes of all gases under the same conditions of temperature and pres-*

sure contain the same number of molecules. This is known as Avogadro's hypothesis.

The Relative Weights of Molecules Determined by Weighing Gases.—If Avogadro's hypothesis is true, then by weighing equal volumes of gaseous substances we can learn the relative weights of the molecules of these substances.

Atomic Weights Learned from Molecular Weights.—If we knew the molecular weights of all compounds we could easily determine the atomic weights of the elements. It would only be necessary to select the smallest quantity of an element which occurs in any of its compounds. Thus, for example, if we were to examine all known oxygen compounds that can be studied in the form of gas or vapor, we should find that the smallest quantity of oxygen found in any molecule is represented by 16.

Valence.—The formulas of the compounds thus far considered have all been determined by exactly the same methods. On comparing the formulas of the simplest hydrogen compounds of chlorine, oxygen, nitrogen, and carbon a curious difference is observed. The formulas are

$$ClH, \qquad OH_2, \qquad NH_3, \qquad CH_4.$$

According to the atomic theory these expressions mean that the molecule of hydrochloric acid consists of 1 atom of chlorine combined with 1 atom of hydrogen; the molecule of water consists of 1 atom of oxygen combined with 2 atoms of hydrogen; the molecule of ammonia of 1 atom of nitrogen and 3 atoms of hydrogen; and the molecule of marsh-gas of 1 atom of carbon and 4 atoms of hydrogen. It appears, therefore, that the atom of oxygen can hold in

combination twice as many hydrogen atoms as the atom of chlorine can; that the atom of nitrogen can hold three times as many; and the atom of carbon four times as many. Other atoms differ from one another in the same way.

That property of an element by virtue of which its atom can hold in combination a definite number of other atoms is called *valence*.

Kinds of Elements.—As far as the number of other atoms which it can hold in combination is concerned, the chlorine atom represents the simplest class of atoms. As one chlorine atom can hold but one hydrogen atom in combination, so one hydrogen atom can hold but one chlorine atom. Either the hydrogen atom or the chlorine atom may be taken as an example of the simplest kind of atom. An element like hydrogen or chlorine is called a *univalent element;* an element like oxygen whose atom can hold two unit atoms in combination is called a *bivalent element;* an element like nitrogen whose atom can hold three unit atoms in combination is called a *trivalent element;* and an element like carbon whose atom can hold four unit atoms in combination is called a *quadrivalent element.* Most elements belong to one or the other of these four classes.

[Calcium forms with chlorine the compound $CaCl_2$. What is the valence of calcium? Potassium and sodium form chlorides of the formulas KCl and $NaCl$ respectively. What is the valence of these elements? Sulphur forms with hydrogen a compound of the formula SH_2. What is the valence of sulphur?]

Substituting Power of the Elements.—In the formation of salts you have seen that the hydrogen of acids is dis-

placed by metals. In such cases one atom of a univalent metal takes the place of one atom of hydrogen, one atom of a bivalent metal takes the place of two atoms of hydrogen, etc. Thus potassium and sodium are univalent. In the formation of potassium nitrate from nitric acid, HNO_3, one atom of potassium displaces one atom of hydrogen in the molecule of nitric acid, forming the salt KNO_3. So also sodium nitrate is $NaNO_3$. In the molecule of sulphuric acid, H_2SO_4, there are two atoms of hydrogen. To displace these, two atoms of a univalent element are required. Thus, potassium sulphate is K_2SO_4, and sodium sulphate is Na_2SO_4. Examples of salts containing bivalent metals are the following: zinc sulphate, $ZnSO_4$, in which one atom of bivalent zinc has displaced the two atoms of hydrogen of the sulphuric acid; barium sulphate, $BaSO_4$, in which one atom of bivalent barium has displaced the two atoms of hydrogen of sulphuric acid. When a bivalent metal forms a salt with an acid like hydrochloric acid, which contains but one atom of hydrogen in the molecule, it is believed that one atom of the metal acts upon two molecules of the acid, thus:

$$Zn + \begin{array}{c} HCl \\ HCl \end{array} = Zn \left\{ \begin{array}{c} Cl \\ Cl \end{array} + H_2, \right.$$

or

$$Zn + 2HCl = ZnCl_2 + H_2.$$
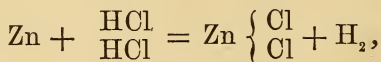
The formula of zinc nitrate is similar, viz., $Zn(NO_3)_2$. In the case of trivalent elements the matter is a little more complicated, but still simple enough if it be borne in mind that a univalent atom takes the place of one atom of hydrogen; a bivalent atom takes the place of two atoms

of hydrogen; a trivalent atom takes the place of three atoms of hydrogen, etc.

CLASSIFICATION OF THE ELEMENTS.

Acid Properties and Basic Properties.—The chemical properties that force themselves upon our attention most prominently in whatever field of chemistry we may be working are those which are known as *acid properties* and *basic properties*. As has already been pointed out, these two kinds of properties are the opposite of each other. No matter how much chemistry may grow, it is certain that the distinction between these two kinds of properties will always be recognized as important.

Acid-forming Elements and Base-forming Elements.—In general, both acids and bases contain hydrogen and oxygen. *There are some elements whose compounds with hydrogen and oxygen have basic properties, and others whose compounds with hydrogen and oxygen have acid properties.* This important fact may be used as the basis of a partial classification of the elements. According to this, we have (1) *acid-forming elements* and (2) *base-forming elements*. Examples of the first class are chlorine, nitrogen, and sulphur. Examples of the second class are sodium, calcium, magnesium, etc. The last mentioned are generally called *metals,* and the acid-forming elements are generally called *non-metals.*

Families of Elements.—Another important fact which is soon recognized in studying the elements is that they fall into families according to their chemical properties, the members of the same family showing striking resemblances

among one another. Thus, there is the *chlorine family,* which includes, besides chlorine itself, bromine, iodine, and fluorine. Further, there is the sulphur family, consisting of the closely related elements sulphur, selenium, and tellurium; besides other families. In all these cases the resemblance between members of the same family is striking.

Families of the Acid-forming Elements.—First, we shall have the following families to deal with:

CHLORINE FAMILY.	SULPHUR FAMILY.	NITROGEN FAMILY.	CARBON FAMILY.
Chlorine,	Sulphur,	Nitrogen,	Carbon,
Bromine,	Selenium,	Phosphorus,	Silicon.
Iodine,	Tellurium.	Arsenic,	
Fluorine.		Antimony.	

As the object of your present study is to get a general idea of the principles of chemistry, it will not be necessary to go into details in dealing with these families. One member of each family, except the sulphur family, having been treated comparatively fully, the other members may be treated briefly. The members of the sulphur family resemble oxygen somewhat, but also differ from it in many respects. It will thus be possible to get a clearer idea of the principles of chemistry than by attempting to study a large number of facts.

CHAPTER XV.

THE CHLORINE FAMILY: CHLORINE, BROMINE, IODINE, FLUORINE.

Introduction.—The three members of this family which show the most marked resemblance are chlorine, bromine, and iodine.

Bromine (*At. Wt.* 80).—This element occurs in nature in company with chlorine. Chlorine, as has been stated, occurs mostly in combination with sodium, as sodium chloride, or common salt. In several of the great salt-beds there is some bromine in the form of sodium bromide, NaBr, and in some places it occurs as potassium bromide, KBr.

Preparation of Bromine.—The method is the same as that made use of for extracting chlorine. In order to get chlorine out of common salt, the salt is first converted into hydrochloric acid, and this is then oxidized. So, too, in order to get bromine out of sodium bromide, the bromide must first be converted into hydrobromic acid, and this then oxidized. The reactions are

$$2NaBr + H_2SO_4 = Na_2SO_4 + 2HBr;$$
$$2HBr + O = H_2O + 2Br.$$
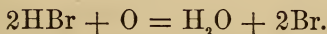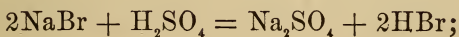
On the large scale bromine is made by treating magnesium bromide, $MgBr_2$, with chlorine:

$$MgBr_2 + 2Cl = MgCl_2 + 2Br.$$
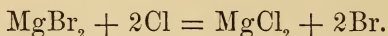
Properties of Bromine. — At ordinary temperatures bromine is a heavy dark-red liquid which is easily converted into a brownish-red vapor. It has an extremely disagreeable odor. Hence its name from a Greek word meaning a stench. Its properties are, in general, like those of chlorine. It acts violently upon organic substances. It attacks the skin and the membranes lining the passages of the throat and lungs. Wounds caused by the liquid coming in contact with the skin are painful and heal with difficulty. It must, therefore, be handled with great care. It combines with many elements directly and with great energy, its compounds with other elements being called *bromides*. While acting in general in the same way as chlorine, it is a somewhat weaker element, so that chlorine drives it out of its compounds and sets it free.

EXPERIMENT 83.—Mix together about 1 gram of potassium bromide and 2 grams of manganese dioxide. Pour upon the mixture, in a good-sized test-tube, sufficient dilute sulphuric acid to cover it. Heat gently. What do you observe? Perform this experiment where there is a good draught.

Hydrobromic Acid, HBr. —The only compound which bromine forms with hydrogen alone is hydrobromic acid. This is in all respects very much like hydrochloric acid.

EXPERIMENT 84.— In a test-tube put a few crystals of potassium bromide. Pour on them a few drops of concentrated sulphuric acid. White fumes of hydrobromic acid and reddish-brown vapor of bromine are noticed. Treat a few crystals of potassium or sodium chloride in the same way. What difference is there

between the two cases? The explanation of the difference observed is that sulphuric acid decomposes hydrobromic acid, setting bromine free, while it does not decompose hydrochloric acid.

Compounds with Hydrogen and Oxygen.—With hydrogen and oxygen bromine forms compounds which resemble very closely those which chlorine forms with the same elements. The principal ones are *bromic*, $HBrO_3$, and *hypobromous acids*, HBrO, which are like chloric and hypochlorous acids.

Iodine, I (*At. Wt.* 127).—This element occurs in nature in combination with sodium, in company with chlorine and bromine, but in smaller quantity than either. It is also found in larger quantity in sea-plants. It is obtained largely from the latter source. On the coasts of Scotland and France the sea-weed which is thrown up by storms is gathered, dried, and burned. The organic portions are thus destroyed [what is the meaning of the word destroyed used in this sense?], and the mineral or earthy portions are left behind as ashes. The incombustible residue is called *kelp*. It contains sodium iodide. At present, in some parts of the ocean, sea-weed is cultivated for the sake of the iodine which it yields. Chili saltpetre, or the natural sodium nitrate found in Chili, contains some iodine in combination partly as sodium iodide and partly as sodium iodate, and this furnishes a considerable quantity of the iodine of commerce.

Preparation of Iodine.—Iodine is prepared from sodium iodide, just as chlorine and bromine are prepared from their compounds with sodium and potassium.

Properties of Iodine.—At ordinary temperatures iodine is a grayish-black, crystallized solid. It melts easily and boils, forming a violet-colored vapor.

EXPERIMENT 85.—Mix about 1 gram potassium iodide with about twice its weight of manganese dioxide. Treat with a little sulphuric acid in a test-tube. Heat gently. Gradually the tube will be filled with the beautiful colored vapor of iodine. In the upper part of the tube some of the iodine will be deposited in the form of crystals of a grayish-black color.

Iodine dissolves slightly in water, easily in alcohol and in a water solution of potassium iodide.

EXPERIMENT 86.—Make solutions of iodine in water, in alcohol, and in a water solution of potassium iodide. Use small quantities in test-tubes.

When a solution containing *free* iodine is treated with a little starch-paste the solution turns blue, in consequence of the formation of a complicated compound of starch and iodine. Bromine and chlorine do not form blue compounds. Advantage is taken of this fact to distinguish between iodine and other members of the family.

EXPERIMENT 87.—Make some starch-paste by covering a few grains of starch in a porcelain evaporating-dish with cold water, grinding this to a paste, and pouring 200–300 c.c. boiling hot water on it. After cooling add a little of this paste to a dilute solution of iodine in potassium iodide. What change takes place? Now add a little of the paste to a diluted water solution of potassium iodide. Is there any change of color? Add a drop or two of a solution of chlorine in water. What takes place? Explain what you have seen. Does chlorine alone form a blue compound with starch?

Hydriodic Acid, HI, is analogous to hydrochloric and hydrobromic acids. It is set free from the *iodides* by treating them with sulphuric acid; but it is even more unstable than hydrobromic acid, and hence breaks down into hydrogen and iodine. The iodine is set free, while the hydrogen acts on the sulphuric acid, as it does in the case of hydrobromic acid.

EXPERIMENT 88.—Treat a few small crystals of potassium iodide with sulphuric acid. [What do you notice?] Compare with the results obtained when potassium bromide and sodium chloride are used.

Fluorine occurs in nature in large quantity, and widely distributed, but always in combination with other elements. It is found chiefly in combination with calcium, as *fluor spar*, or *calcium fluoride*, CaF_2, and in combination with sodium and aluminium, as *cryolite*, a mineral which occurs abundantly in Greenland, and has the composition $3NaF . AlF_3$, or Na_3AlF_6, being a complex compound of sodium fluoride and aluminium fluoride. It is prepared by passing an electric current through liquid hydrofluoric acid containing potassium fluoride in solution in a vessel of platinum or copper.

It is the most active of all the elements at ordinary temperatures. It is a greenish-yellow gas.

Hydrofluoric Acid, HF, is made from fluor spar by treating it with sulphuric acid. The action is of the same kind as that which takes place when hydrochloric acid is liberated from sodium chloride:

$$CaF_2 + H_2SO_4 = CaSO_4 + 2HF.$$
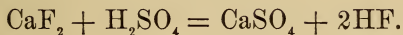
Hydrofluoric acid is a colorless gas, with strong acid properties. It greatly irritates the membranes lining the throat and lungs, and hence care should be taken not to inhale it. It acts upon glass, decomposing it, and must therefore be kept in vessels of rubber, lead, or platinum, upon which it does not act.

Etching on Glass.—The acid is used for etching on glass, particularly for marking scales on thermometers, barometers, and other graduated glass instruments. A

solution of the gas in water is manufactured for this purpose and kept in rubber bottles.

EXPERIMENT 89.—A lead or platinum vessel put a few grams (5–6) of powdered fluor spar, and pour on it enough concentrated sulphuric acid to make a thick paste. Cover the surface of a piece of glass with a thin layer of wax or paraffin, and through this scratch some letters or figures, so as to leave the glass exposed where the scratches are made. Put the glass with the waxed side downward over the vessel containing the fluor spar, and let it stand for some hours. Then take off the glass, scrape off the coating, and the figures which were marked through the wax or paraffin will be found *etched* on the glass.

Comparison of the Members of the Chlorine Family.—In considering, first, the physical properties of these elements, you notice that all form colored gases or vapors. At ordinary temperatures fluorine and chlorine are gases, bromine is a liquid, and iodine a solid. In regard to their chemical conduct, it may be said that, in general, fluorine is the most active; chlorine comes next in order, then bromine, and lastly iodine.

Their Compounds.—The compounds formed by the three elements chlorine, bromine, and iodine with hydrogen and oxygen have analogous compositions, and are formed by analogous reactions. Thus, there are the hydrogen compounds:

$$HCl, \quad HBr, \quad and \ HI;$$

and the compounds with hydrogen and oxygen:

$$HClO, \quad HBrO. \quad —$$
$$HClO_2. \quad — \quad —$$
$$HClO_3, \quad HBrO_3, \quad HIO_3.$$
$$HClO_4, \quad \quad \quad HIO_4.$$
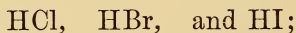
Relations between the Atomic Weights.—On comparing the atomic weights of chlorine, bromine, and iodine, it will be seen that the atomic weight of bromine, which is 80, is nearly the mean of the atomic weights of chlorine and iodine.

$$35.5 \; + \; 127 \; = \; 162.5;$$

$$\underset{\substack{\text{At. Wt. of} \\ \text{chlorine.}}}{} \qquad \underset{\substack{\text{At. Wt. of} \\ \text{iodine.}}}{}$$

and $\dfrac{162.5}{2} = 81.25$, which is nearly the atomic weight of bromine.

Relation between the Properties of the Elements and their Atomic Weights.—*The properties of the three elements —chlorine, bromine, and iodine—vary with the variations in their atomic weights, or with the weights of their atoms.* The gradation in properties takes place in the order fluorine, chlorine, bromine, iodine, and this is also the order in which the atomic weights increase. This may be a mere coincidence, but we shall find that in the other families there are similar indications of a close connection between the weights of the atoms of the elements and their physical and chemical properties.

CHAPTER XVI.

THE SULPHUR FAMILY: SULPHUR, SELENIUM, TELLURIUM.

Sulphur, S (*At. Wt.* 32).—The principal member of this family is sulphur. In nature it is often accompanied by small quantities of selenium, and sometimes by tellurium. It has been known in the elementary form from the earliest times, for the reason that it occurs abundantly in this form in nature. It is found particularly in the neighborhood of volcanoes, as in Sicily, which is the chief source of the sulphur of commerce. It occurs, further, in combination with many metals as sulphides,—as in iron pyrites, FeS_2; copper pyrites, $FeCuS_2$; galenite, PbS, etc.; in combination with metals and oxygen as sulphates,—for example, as calcium sulphate, or gypsum, $CaSO_4 + 2H_2O$; barium sulphate, or heavy spar, $BaSO_4$; lead sulphate, $PbSO_4$; and in a few vegetable and animal products in combination with carbon, hydrogen, and, generally, with nitrogen.

Extraction of Sulphur from its Ores.—When taken from the mines, sulphur is mixed with many earthy substances from which it must be separated. This separation is accomplished by piling the ore in such a way as to leave

passages for air. The piles are covered with some material to prevent free access of air, and the mass is then lighted below. A part of the sulphur burns, and the heat thus furnished melts the rest of the sulphur. The molten sulphur runs down to the bottom of the pile, and is drawn off from time to time.

[If the pile were not protected from free access of air what would become of the sulphur? What analogy is there between this process and that made use of in making charcoal? What are the essential differences between the two processes?]

How Sulphur is Refined.—The crude brimstone first obtained is afterwards refined by distillation, and it is this distilled sulphur that is met with in commerce under the names "roll brimstone," "stick sulphur," and "flowers of sulphur." The distillation is carried on in earthenware retorts connected with large chambers of brick-work. When the vapor of sulphur first comes over into the condensing chamber it is suddenly cooled, and hence deposited in the form of fine powder. This is what is called "flowers of sulphur." After the distillation has continued for some time the vapor condenses in the form of a liquid, which collects at the bottom of the chamber. This is drawn off into wooden moulds and takes the form of "roll brimstone" or "stick sulphur."

Properties of Sulphur.—Sulphur is a yellow, brittle substance which at $-50°$ is almost colorless. It melts at $114°.5$, forming a thin, straw-colored liquid. When heated to a higher temperature it becomes darker and darker in color, and at $200°$ to $250°$ it is so thick that the vessel containing it may be turned upside down without

danger of running out. Finally, at 448°.4 it boils and is then converted into a brownish-yellow vapor.

EXPERIMENT 90.—Distil about 10 grams of roll sulphur from an ordinary glass retort. The retort should not be connected with a condenser. Notice the changes above described. Collect the liquid sulphur which passes over in a beaker-glass containing cold water.

The sulphur collected in this experiment is at first quite elastic. On standing it becomes brittle.

Crystals of Sulphur.—When molten sulphur solidifies, or when it is deposited from a solution, its particles arrange themselves in regular forms called crystals. But, strange to say, the crystals formed from molten sulphur are entirely different from those deposited from solutions of sulphur. Substances which crystallize in two distinct forms are called *dimorphous*. Carbon, like sulphur, crystallizes in two different forms [what are they?], and is hence dimorphous.

EXPERIMENT 91.—In a covered sand or Hessian crucible melt about 20 grams of roll sulphur. Let it cool slowly, and when a thin crust has formed on the surface make a hole through this and pour out the liquid part of the sulphur. The inside of the crucible will be found lined with honey-yellow needles. Take out a few crystals and examine them.—Are they brittle or elastic? What is their color? Are they opaque, transparent, or translucent?—Lay the crucible aside, and in the course of a few days again examine the crystals.—What changes, if any, have taken place?

Solution of Sulphur.—Sulphur is insoluble in water, slightly soluble in alcohol and ether. It dissolves in the liquid compound of carbon and sulphur known as carbon bisulphide, CS_2, and from this solution it is deposited in crystals quite different from those obtained in Experiment 91.

EXPERIMENT 92.—Dissolve 2 to 3 grams roll sulphur in 5 to 10 c.c. carbon disulphide. Put the solution in a small beaker, and allow the carbon bisulphide to evaporate by standing in the air. What is the appearance of the crystals? Are they dark yellow or bright yellow? Are they brittle or elastic? [State in tabular form the properties of the two allotropic forms of sulphur.]

Chemical Conduct of Sulphur.—Sulphur combines with oxygen when heated to a sufficiently high temperature. The product is sulphur dioxide, SO_2. [Is there any analogy between carbon and sulphur in this respect?] It combines readily with most metals, forming sulphides. Its combination with iron has already been shown in Experiment 12. It also combines with copper, the act being accompanied by light and heat.

EXPERIMENT 93.—In a wide test-tube heat some sulphur to boiling. Introduce into it small pieces of copper-foil or sheet copper. Or hold a narrow piece of sheet copper so that the end just dips into the boiling sulphur. What evidence have you that action takes place?

Hydrogen Sulphide, Sulphuretted Hydrogen, H_2S.— When hydrogen is passed over highly heated sulphur the two elements combine to form hydrogen sulphide. [Is there any analogy between this process and the formation of water by the burning of hydrogen?] This compound of sulphur and hydrogen occurs in nature in solution in the so-called "sulphur waters," which are met with in many parts of this and other countries. It also issues from the earth in some places. It is formed by heating organic substances that contain sulphur, just as water is formed by heating organic substances that contain oxygen, and ammonia by heating such as contain nitrogen. It is formed, further, by decomposition of organic substances which contain sulphur, as, for example, the albumen of

eggs. The odor of rotten eggs is partly due to the forma-
tion of hydrogen sulphide. [How is it that paraffin,
p. 117, heated with sulphur gives off hydrogen sulphide?]

Preparation of Hydrogen Sulphide.—It is made in the
laboratory by treating a sulphide with an acid. When
sulphuric acid acts upon iron sulphide, hydrogen sulphide
is given off thus:

$$FeS + H_2SO_4 = FeSO_4 + H_2S.$$
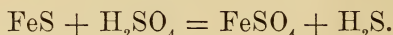
Hydrochloric acid acts in a similar way:

$$FeS + 2HCl = FeCl_2 + H_2S.$$

EXPERIMENT 94.—Arrange an apparatus as shown in Fig. 14.
Put a small handful of sulphide of iron, FeS, in the flask, and
pour *dilute* sulphuric acid upon it. Pass the gas through a little
water contained in the wash-cylinder *A*. Pass some of the gas
into water. What evidence have you that it dissolves?—Collect
some by displacement of air. It is heavier than air (specific grav-
ity 1.178). Should the vessel be placed with the mouth down or
up? Set fire to some of the gas contained in a cylinder. If there
is free access of air the sulphur burns to sulphur dioxide, and the
hydrogen to water.

Properties of Hydrogen Sulphide.—Hydrogen sulphide,
or, as it is commonly called, sulphuretted hydrogen, is a
colorless, transparent gas. It has a disagreeable odor,
somewhat resembling that of rotten eggs. It is poisonous
when inhaled in any quantity. It dissolves in water,
forming a solution which has the odor of the gas. Most
metals when heated in the gas are converted into sulphides.
Thus, when it is passed over heated iron this reaction
takes place:

$$Fe + H_2S = FeS + H_2.$$
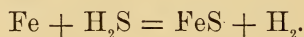
[What takes place when water vapor is passed over
heated iron?]

Precipitation of Sulphides.—Many of the sulphides are insoluble in water. Hence, when hydrogen sulphide is passed through solutions containing metals in the form of soluble salts, the insoluble sulphides are thrown down, or *precipitated*.

EXPERIMENT 95.—Pass hydrogen sulphide successively through solutions containing a little *lead nitrate*, *zinc sulphate*, and *arsenic chloride* prepared by dissolving a little white arsenic, or *arsenic trioxide*, As_2O_3, in dilute hydrochloric acid. What do you observe in each case ?—The substances formed are respectively the sulphides of lead, zinc, and arsenic. The reaction in the case of zinc sulphate is represented thus :

$$ZnSO_4 + H_2S = ZnS + H_2SO_4.$$

Chemical Analysis.—In dealing with chemical substances the first thing we have to determine is their composition, or, in other words, we have to analyze them. For this purpose we must first know the properties of the elements and their conduct towards chemical substances. To facilitate the process of analysis the mixture to be examined is usually brought into solution and then treated successively with certain substances, the effect being observed in each case. Suppose we had a solution containing most of the metallic elements in the form of salts. If we were to pass hydrogen sulphide through this solution, some of the metals would be precipitated as sulphides, while others would remain in solution, as their sulphides are soluble. The precipitated sulphides could then be filtered off and examined, and the filtered solution also could be further examined. Hydrogen sulphide is constantly made use of in the laboratory for the purposes of analysis.

COMPOUNDS OF SULPHUR WITH OXYGEN, AND WITH
HYDROGEN AND OXYGEN.

Formation of the Compounds of Sulphur.—When sulphur
burns in the air, the *dioxide*, SO_2, is formed.   Under
certain conditions the dioxide combines with more oxygen,
forming the *trioxide*, SO_3.   When sulphur dioxide acts
upon water, *sulphurous acid* is formed:

$$SO_2 + H_2O = H_2SO_3.$$
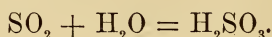
[What analogy is there between the acid thus formed
and carbonic acid?]

When the trioxide combines with water, *sulphuric acid*
is formed:

$$SO_3 + H_2O = H_2SO_4.$$

Sulphur Dioxide, SO_2.—This compound is formed by
burning sulphur in the air or in oxygen.   It issues from
volcanoes in large quantities.   It can be prepared by
heating copper with sulphuric acid and by
treating a sulphite with sulphuric acid.
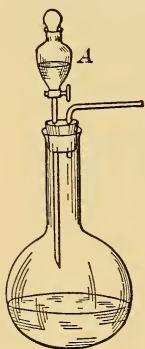
EXPERIMENT 96.—Arrange an apparatus as
shown in Fig. 36.   *A* is a funnel-tube provided
with a stop-cock.   In the flask put a 40 per cent
solution of acid sodium sulphite, $HNaSO_3$; in the
funnel, after closing the stop-cock, put ordinary
concentrated sulphuric acid.   Open the stop-cock
very little so that the sulphuric acid *drops* into the
solution below.   A regular evolution of sulphur
dioxide can thus be maintained.   Pass some of the
gas into a bottle containing water.   Fill a vessel
by displacement of air.   It is more than twice
as heavy as air.   See whether the gas will burn or support com-
bustion.

FIG. 36.

$$2HNaSO_3 + H_2SO_4 = Na_2SO_4 + 2SO_2 + 2H_2O.$$
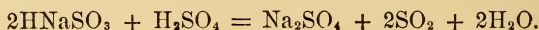
Properties of Sulphur Dioxide.—Sulphur dioxide is a colorless gas of an unpleasant, suffocating odor, familiar to every one as that of burning sulphur-matches. Water dissolves it readily. It bleaches readily, and stops fermentation.

EXPERIMENT 97.—Burn a little sulphur in a porcelain crucible under a bell-jar. Place over the crucible on a tripod some flowers. In the atmosphere of sulphur dioxide the flowers will be bleached.

Uses of Sulphur Dioxide.—It is used extensively for the purpose of bleaching wool, silk, straw, paper, etc.; and, further, to preserve liquids that have a tendency to undergo fermentation. If left in the air, fruit-juices become sour in consequence of fermentation. As sulphur dioxide prevents fermentation, the juices are kept sweet if treated with something which gives off the gas, as, for example, a sulphite. The principal use of sulphur dioxide is in the manufacture of sulphuric acid. For this purpose it is made in enormous quantities.

Sulphurous Acid and Sulphites.—The solution of sulphur dioxide in water has acid properties, and contains the acid H_2SO_3. By neutralizing the solution with bases, the *sulphites,* or salts of sulphurous acid, are obtained. The sulphites are analogous to the carbonates in composition, and suffer the same decomposition when treated with acids. When a carbonate is treated with an acid, carbon dioxide is given off. So, also, when a sulphite is treated with an acid, sulphur dioxide is given off:

$$Na_2SO_3 + H_2SO_4 = Na_2SO_4 + H_2O + SO_2;$$
$$Na_2SO_3 + 2HCl = 2NaCl + H_2O + SO_2.$$
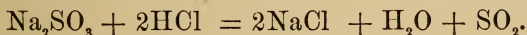
Sulphuric Acid, H_2SO_4.—Salts of sulphuric acid are found in nature, as gypsum, heavy spar, etc. It cannot easily be prepared from its salts, as hydrochloric and nitric acids are prepared, and is made exclusively by oxidizing sulphur dioxide. The reactions involved in the manufacture of sulphuric acid are:

$$S \quad + O_2 \quad = SO_2;$$
$$SO_2 \quad + H_2O = H_2SO_3;$$
$$H_2SO_3 + O \quad = H_2SO_4.$$
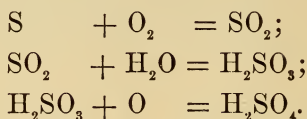
Or sulphur dioxide is oxidized to the trioxide, and this then treated with water, in which case the reactions are:

$$SO_2 + O \quad = SO_3;$$
$$SO_3 + H_2O = H_2SO_4.$$
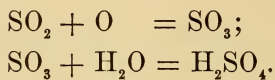
How Nitric Oxide Acts in Oxidizing Sulphurous Acid.—The older method of making sulphuric acid depends partly upon the power of nitric oxide, NO, to combine directly with the oxygen of the air to form nitrogen peroxide, NO_2. Nitrogen peroxide gives up half its oxygen to sulphurous acid, and is itself thus reduced to nitric oxide. If, therefore, sulphur dioxide, water, and nitrogen peroxide are brought together, the first action is represented thus:

$$SO_2 + H_2O + NO_2 = H_2SO_4 + NO.$$
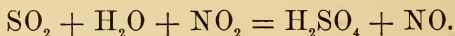
Now, if air is supplied, the nitric oxide is converted into the peroxide:

$$NO + O = NO_2.$$

The peroxide acting upon a further quantity of sulphur dioxide and water is again reduced, and so on indefinitely. It will thus be seen that, starting with a small quantity

of nitric oxide, it should be possible to convert a large quantity of sulphur dioxide into sulphuric acid.

Manufacture of Sulphuric Acid.—In the manufacture of sulphuric acid by the older and ordinary method sulphur or iron pyrites, FeS_2, is burned. In the former case, the only product of the combustion is sulphur dioxide; in the latter case, the sulphur forms sulphur dioxide, and the iron is converted into an oxide, Fe_2O_3. The sulphur dioxide thus formed is conducted into large chambers lined with lead, for the reason that sulphuric acid does not act upon lead, while it does act upon most other common metals. Instead of starting with nitric oxide, nitric acid is passed into the chambers, and water in the form of steam. The first action between the nitric acid, steam, and sulphur dioxide is this:

$$2HNO_3 + 3SO_2 + 2H_2O = 3H_2SO_4 + 2NO.$$

From this point sulphur dioxide, water, and nitric oxide are brought into action, and the chief reactions are those described above.

A Leaden Chamber.—The arrangement of a leaden chamber is shown in Fig. 37. The furnace in which the

Fig. 37.

sulphur or iron pyrites is burned is represented by *f*. Steam from the boiler *b* is forced into the chamber

through jets. The nitric acid is formed from sodium nitrate and sulphuric acid in the furnace *n*. A good draught is kept up by means of a high chimney.

New Method for the Manufacture of Sulphuric Acid.—A simpler method than that above described has recently been devised. This consists in making *sulphur trioxide* by causing sulphur dioxide and oxygen to unite. Under ordinary circumstances sulphur dioxide does not combine with more oxygen. When it is passed with air or oxygen over various substances such as platinum and an oxide of iron in a finely divided state, it unites with oxygen to form the trioxide. When the trioxide is brought together with water sulphuric acid is formed.

Ordinary Sulphuric Acid: Oil of Vitriol.—The acid obtained from the chambers is evaporated in lead pans, and afterwards in platinum or glass or cast-iron pans. The strong acid thus obtained is the concentrated sulphuric acid of commerce, which is commonly called *oil of vitriol*. It is an oily liquid, usually somewhat colored by impurities.

The *pure acid* is a colorless liquid at ordinary temperatures. When cooled down it forms crystals. It decomposes the salts of most other acids, setting the acids free and forming sulphates. You have already had illustrations of this power in the liberation of nitric and hydrochloric acids from their salts by treatment with sulphuric acid.

[Give the equations representing the action which takes place when common salt and potassium nitrate are treated with sulphuric acid.]

Sulphuric Acid Combines with Water.—Sulphuric acid has a very strong tendency to absorb water and form compounds with it. A great deal of heat is formed in this

action. This fact has been repeatedly illustrated in experiments already performed; and attention has been called to the necessity for caution in mixing the liquids. The acid acts upon organic substances containing hydrogen and oxygen, and extracts them in the proportions to form water. A piece of wood is charred, if put in the acid, in consequence of the abstraction of hydrogen and oxygen. [How is carbon monoxide prepared? How is wood charred in the preparation of charcoal? Is there any analogy between the preparation of charcoal in the ordinary way and by the action of sulphuric acid?]

Wounds caused by sulphuric acid are painful and heal with difficulty.

Importance of Sulphuric Acid.—Sulphuric acid is the most important manufactured chemical substance. Most chemical industries depend upon it. Among the many uses to which it is put are the making of "soda" or sodium carbonate, which is necessary for the manufacture of soap and glass; the making of phosphorus, of artificial fertilizers, of glucose, of nitroglycerin, the refining of petroleum, etc., etc.

Monobasic and Dibasic Acids.—Sulphuric acid differs markedly from nitric and hydrochloric acids in one respect. It has the power to form two different salts with the same metal, in one of which there is relatively twice as much of the metallic element as in the other. If to a given quantity of sulphuric acid there is aded only half the quantity of caustic potash required to neutralize it, a salt is formed which crystallizes. It has the composition represented by the formula $KHSO_4$. If nitric acid is treated in the same way, only half the acid is acted on,

and this forms ordinary potassium nitrate, KNO_3, the rest of the acid being left unacted upon. In the case of sulphuric acid two reactions are possible, viz.:

$$H_2SO_4 + KOH = KHSO_4 + H_2O;$$
$$H_2SO_4 + 2KOH = K_2SO_4 + 2H_2O.$$
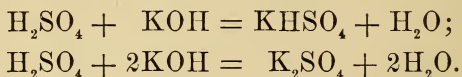
In the case of nitric acid only one reaction is possible under ordinary circumstances:

$$HNO_3 + KOH = KNO_3 + H_2O.$$
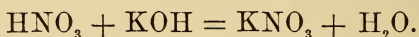
Acids which, like sulphuric acid, have the power to form two salts with the same metal are called *dibasic acids*. Acids which, like nitric acid, have the power usually to form only one salt with the same metal are called *monobasic acids*. This power is connected with the number of replaceable hydrogen atoms contained in the molecule of the acid. An acid containing two replaceable hydrogen atoms in its molecule is dibasic; one containing only one replaceable hydrogen atom in its molecule is monobasic.

Acid, Neutral, and Normal Salts.—A dibasic acid yields two classes of salts: (1) those in which all the hydrogen is replaced, and (2) those in which half the hydrogen is replaced by metal. The former are called *normal salts*, the latter *acid salts*. Normal salts are generally neutral, and are sometimes called neutral salts.

Carbon Bisulphide, CS_2.—Sulphur forms with carbon a compound called carbon bisulphide, which has the composition CS_2. It is made by bringing carbon and sulphur together at high temperatures. It is a liquid that boils at 47°. That it dissolves sulphur has been shown in

Experiments 11 and 92. It also dissolves many other substances, as, for example, rubber.

Selenium, Tellurium, and their Compounds.—These elements are comparatively rarely met with. In general their properties are similar to those of sulphur, and they form compounds analogous to the principal compounds of sulphur.

Relations between the Atomic Weights of Sulphur, Selenium, and Tellurium.—The relation between the atomic weights of the members of the sulphur family is like that already noticed between the atomic weights of the members of the chlorine family. It is shown thus:

$$\underset{\substack{\text{At. Wt. of} \\ \text{sulphur.}}}{32} + \underset{\substack{\text{At. Wt. of} \\ \text{tellurium.}}}{127} = 159;$$

and $\dfrac{159}{2} = 79.5$, which is nearly 79, the atomic weight of selenium.

CHAPTER XVII.

THE NITROGEN FAMILY: NITROGEN, PHOSPHORUS, ARSENIC, AND ANTIMONY.

BORON AND SILICON.

Phosphorus, P (*At. Wt.* 31).—Phosphorus occurs in the form of phosphates, or salts of phosphoric acid. The chief of these is calcium phosphate, which is the principal constituent of the minerals *phosphorite* and *apatite,* and of the ashes of bones.

Phosphorus Made from Bones.—It is made from bone-ash, which contains a large proportion of calcium phosphate. The ash is first mixed with sulphuric acid. Then the compound thus obtained is mixed with charcoal and heated, when phosphorus distils over. It is cast into sticks under water, and kept under water.

Properties.—It is colorless or slightly yellow and translucent. At ordinary temperatures it can be cut like wax, but it becomes hard and brittle at lower temperatures. It melts at 44°, and boils at 290°. Unless carefully protected from the light its appearance changes. It becomes opaque and dark in color, and finally dark red. This change can be hastened by heating the phosphorus in a sealed tube to 250°. Ordinary phosphorus is insoluble in water, but soluble in carbon bisulphide. In contact

with the air it gives off fumes which emit a pale light visible in a dark room. It takes fire when rubbed or cut, and must hence be handled with great care. It should always be cut under water, and never held in the hand. It not only combines with oxygen easily, but with other elements, such as chlorine, bromine, and iodine.

EXPERIMENT 98.—Bring together in a porcelain crucible or evaporating-dish a little phosphorus and iodine. It will be seen that simple contact is sufficient to cause the two substances to act upon each other. Direct combination takes place, and the action is accompanied by light and heat.

Phosphorus is very poisonous. Its vapor produces a disease of the bones.

Red Phosphorus.—The red substance formed when ordinary phosphorus is left in the light, or heated without access of air, is a second variety of phosphorus, known as red phosphorus. This differs from ordinary phosphorus as much as graphite differs from the diamond. Ordinary phosphorus is very active, combining readily with oxygen; it is soluble in carbon bisulphide; and is poisonous. Red phosphorus, on the other hand, is inactive. It does not change in the air, and requires to be heated to a comparatively high temperature before it will combine with oxygen; it is insoluble in carbon bisulphide, and is not poisonous. It is converted into the ordinary variety when heated to about 300°. [Make out a tabular comparison of the properties of the two allotropic forms of phosphorus.]

Uses of Phosphorus.—The principal use of phosphorus is in the manufacture of matches. Ordinary friction-matches are tipped with a mixture of phosphorus, glue, and potassium chlorate. "Safety-matches" are usually tipped with potassium chlorate and antimony sulphide.

The surface upon which they are rubbed is made of red phosphorus, black oxide of manganese, and glue. Mixed with flour, phosphorus is frequently used as a rat-poison.

Compounds of Phosphorus with Oxygen and with Hydrogen and Oxygen.—When phosphorus is burned in the air or in oxygen it is converted into the oxide, P_2O_5. This combines with water in different proportions, forming two distinct acids, known as *metaphosphoric* and *orthophosphoric acids*:

$$P_2O_5 + \quad H_2O = 2HPO_3;$$
<div align="center">Metaphosphoric acid.</div>

$$P_2O_5 + 3H_2O = 2H_3PO_4.$$
<div align="center">Orthophosphoric acid.</div>
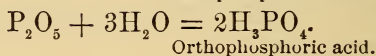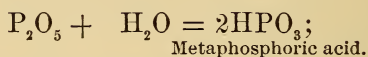
Orthophosphoric or Ordinary Phosphoric Acid, H_3PO_4, is the principal compound of phosphorus. It is the final product of the action of air and moisture on phosphorus. As has been stated, it occurs in nature as the calcium salt in phosphorite and apatite. This salt is also the chief constituent of bone-ash. It is a solid crystallized substance, and is made by treating bone-ash with sulphuric acid, or by oxidizing phosphorus. It has the power of forming three distinct salts with the same metal, and is hence called *tribasic*. With sodium, for example, it forms the three salts Na_3PO_4, Na_2HPO_4, and NaH_2PO_4. Its normal calcium salt—that is to say, the one in which all the three acid hydrogen atoms are replaced by calcium— has the formula $Ca_3(PO_4)_2$, three bivalent calcium atoms replacing six atoms of hydrogen.

Arsenic and its Compounds.—*Arsenic, As (At. Wt. 75),* occurs in nature in combination with metals,—as, for example, iron, copper, cobalt, nickel, etc.,—and in combination with oxygen as the oxide As_2O_3. It has a metallic

lustre. When heated to quite a high temperature in the air it takes fire, and burns with a bluish flame, giving off a smoke which has the odor of garlic and is poisonous. It combines directly with most elements. In the elementary form it is only slightly poisonous, but when oxidized it becomes very poisonous.

Arsine, Arseniuretted Hydrogen, AsH_3.—This compound, which in composition is analogous to ammonia, NH_3, is made by bringing a compound of arsenic into a mixture from which hydrogen is being evolved.

EXPERIMENT 99.—Arrange an apparatus as shown in Fig. 38. The first horizontal tube contains coarsely granulated calcium chloride. Put some granulated zinc in the flask and pour dilute
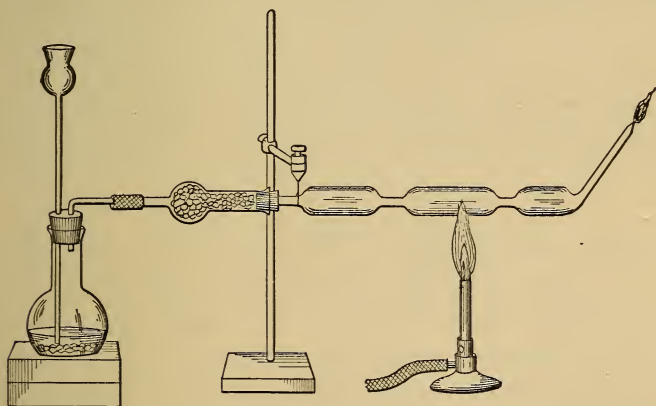
FIG. 38.

sulphuric acid on it. When the air is all out of the vessel and the hydrogen is lighted, add slowly a little of a solution of arsenic oxide, As_2O_3, in dilute hydrochloric acid. What change takes place in the flame? Is the color changed? Are fumes given off? (See Experiment 100.)

Arsine is a colorless gas. It is very poisonous and has an unpleasant odor. When lighted it burns with a bluish-

white flame. It is very unstable, breaking up into arsenic and hydrogen when heated. When a cold object, as a piece of porcelain, is brought into the flame of burning arsine, the arsenic is deposited in the form of a dark spot.

Detection of Arsenic in Cases of Poisoning.—The conduct of arsine is taken advantage of for the purpose of detecting the presence of arsenic. It is extensively used in examining the stomach and other viscera of human beings in cases of suspected poisoning. The method used is known as *Marsh's test.*

EXPERIMENT 100.—Into the flame of the burning hydrogen and arsine produced in the last experiment introduce a piece of porcelain, as the bottom of a small porcelain dish or a crucible, or a bit of a broken plate, and notice the appearance of the spots. Heat by means of a Bunsen burner the tube through which the gas is passing, which should be of hard glass. Just in front of the heated place there will be deposited a thin layer of metallic arsenic, commonly called a mirror of arsenic. This deposit is due to the decomposition of the arsine into arsenic and hydrogen by heat.

Arsenic Trioxide, As_2O_3.—When arsenic is burned in the air or oxygen it forms the trioxide. [Compare with phosphorus in this respect.] This substance, which is what is commonly called *arsenic,* or *white arsenic,* is made by heating certain natural compounds of arsenic and metals in contact with the air. Under these circum-stances both the metal and the arsenic are oxidized, and the oxide of arsenic, being volatile, passes off and is condensed and collected in large chambers of mason-work. It is a colorless, glassy mass. It is difficultly soluble in water, more easily in hydrochloric acid. It has a weak, disagreeably sweet taste, and acts very poisonously. It is

probably more frequently used as a poison than any other substance. Minute quantities can be detected by the chemist with absolute certainty. It is easily reduced by means of carbon.

EXPERIMENT 101.—Mix together about equal small quantities of arsenic oxide and finely powdered charcoal. Heat the mixture in a small dry tube of hard glass, closed at one end. The arsenic that is set free will be deposited on the walls of the tube in the form of a mirror, like that obtained in Experiment 100.

Antimony, Sb (*At. Wt.* 120), occurs most frequently in combination with sulphur as the sulphide Sb_2S_3. It is a silver-white, metallic-looking substance. At ordinary temperatures it is not changed by contact with the air; but when heated to a sufficiently high temperature it takes fire and burns, forming the white oxide.

Stibine, Antimoniuretted Hydrogen, SbH_3.—This compound is made by the same method as that described under Arsenic.

EXPERIMENT 102.—Make some stibine, using a solution of tartar emetic, a substance containing antimony.

Its properties are much like those of arsine. It burns with a similar flame, and is decomposed in the same way.

EXPERIMENT 103.—Introduce a piece of porcelain in the flame and notice the deposit or antimony spot. It is darker and more smoky than the arsenic spot. There are other differences in properties, but they need not be treated of here.

Boron, B (*At. Wt.* 11).—Boron may conveniently be treated of in connection with the members of the nitrogen family, as some of its properties suggest those of the members of that family. At the same time, it has peculiarities which distinguish it from these elements.

It occurs in nature in the form of *boric*, or *boracic acid*, in some hot springs, or as salts of this acid, particularly the sodium salt, or *borax*. It is prepared by treating the oxide, B_2O_3, at a very high temperature with sodium or aluminium. Under proper conditions it is obtained in the form of crystals, which are almost as hard as diamonds.

Tetraboric Acid, $H_2B_4O_7$, is the form of boric acid from which borax is derived. The formula of borax is $Na_2B_4O_7 + 10H_2O$.

THE CARBON FAMILY: CARBON AND SILICON.

Occurrence of Silicon.—Carbon, as you have seen, occurs in every living thing. It is interesting to note that silicon, which in some respects resembles carbon in its chemical properties, is one of the most important constituents of the mineral or inorganic parts of the earth. It occurs chiefly in the form of the oxide, SiO_2, commonly called silica, or silicon dioxide; and in combination with oxygen and several of the common metals, particularly with sodium, potassium, aluminium, magnesium, and calcium, in the form of the silicates.

Great Abundance of Silicon.—Next to oxygen silicon occurs in largest quantity in the earth. There are extensive mountain-ranges consisting almost entirely of silicon dioxide, SiO_2, in the form known as *quartz* or *quartzite*. Other ranges are made up of silicates, which are compounds formed by a combination of silicon dioxide and bases. The clay of valleys, river-beds, etc., also contains silicon in large quantity, while the sand found so abundantly at the seashore is mostly silicon dioxide, SiO_2.

The Element Silicon.—Unlike carbon, silicon is never found in nature in the uncombined state. It is an extremely difficult thing to decompose the oxide in such a way as to get the element. Under proper conditions silicon can be obtained in the form of crystals which have a gray color and are harder than glass.

Silicides are compounds of silicon with other elements, as, for example, with carbon. These two elements combine forming an interesting compound, *carbon silicide*, CSi, which is manufactured on the large scale under the name of *carborundum*. It is made by heating a mixture of quartz sand, coke, and common salt in an electric furnace. It is a very stable substance, and is extremely hard, so that it is used as a substitute for emery.

Silicic Acid.—There are several varieties of silicic acid, all of which are, however, derived from an acid of the formula H_4SiO_4, or normal silicic acid. When this is set free from its salts it loses water, and is changed to ordinary silicic acid, H_2SiO_3:

$$H_4SiO_4 = H_2SiO_3 + H_2O.$$

When heated, this second form of silicic acid is converted into the dioxide SiO_2:

$$H_2SiO_3 = SiO_2 + H_2O.$$

Silicon Dioxide, Silicic Anhydride, SiO_2.—As already stated, this substance occurs very abundantly in nature and in many different forms. *Quartz*, or *rock crystal*, is pure crystallized silicon dioxide; *quartzite* is a coarse-grained substance made up of small crystals of quartz, usually colored. Agate, amethyst, and carnelian are

varieties of quartz colored by foreign substances. Silica also occurs in the stalks of some plants, giving them firmness, and in some cases making them so hard that they are valuable for polishing.

Some of the more important silicates, as water-glass, glass, and the natural silicates, will be treated of farther on.

CHAPTER XVIII.

BASE-FORMING ELEMENTS—GENERAL CONSIDERATIONS.

Distinction between Acid-forming and Base-forming Elements.—The meaning of the name base-forming elements is that the compounds of these elements with hydrogen and oxygen are bases, or, in other words, have the power to neutralize acids and form salts. But the distinction between acid-forming and base-forming elements is not a sharp one, for the reason that there are some elements which form both acids and bases.

Base-forming Elements.—The base-forming elements will be taken up in the following order:

1. The *Potassium Family*, the principal members of which are potassium and sodium.

2. The *Calcium Family*, the principal members of which are calcium, barium, and strontium.

3. The *Magnesium Family*, the principal members of which are magnesium and zinc.

4. The *Silver Family*, consisting of silver, copper, and mercury.

5. The *Aluminium Family*, of which aluminium is the only well-known member.

6. The *Iron Family*, consisting of iron, cobalt, and nickel.

7. The *Manganese Family*, of which manganese is the only representative. There are some points of resemblance between manganese and the members of the chlorine family.

8. The *Chromium Family*, of which chromium is the principal member. There are some points of resemblance between chromium and the members of the sulphur family.

9. The *Bismuth Family*, of which bismuth is the only representative. Between it and the members of the nitrogen family there are some points of resemblance.

10. The *Lead Family*, the principal members of which are lead and tin.

11. The *Palladium Family*, consisting of three rare elements.

12. The *Platinum Family*, the principal members of which are platinum and gold.

Large Number of Base-forming Elements.—You see that there are many more base-forming than acid-forming elements, and it is a serious undertaking to become thoroughly acquainted with all the elements included under this head. For the present it will be best to confine our attention to a few of the most important of the elements.

Metallic Properties.—The base-forming elements are those which are usually called metals. The name metal is applied to those elements which have what is known as a metallic lustre, are opaque, and are good conductors of electricity. Gradually the name metal has come to mean

an element that has the power to displace the hydrogen of acids and form salts.

Classes of Metal Derivatives.—As the metals or base-forming elements all combine with oxygen, sulphur, chlorine, and also form salts with all acids, it follows that under each one there must be a large number of compounds. A thorough study of each metal would include the following subjects:

1. *Its Occurrence in Nature.*—Under this head we should become acquainted with those natural compounds of the metals known as *minerals*. Those minerals from which the metals are extracted for practical purposes are called *ores*.

2. *Extraction of the Metals from their Ores.*—The study of this subject is the object of *metallurgy*.

3. *The Properties of Metals.*—As you will find, metals differ very markedly from one another. Some are light, floating on water, as potassium, sodium, etc.; some are extremely heavy, as lead, platinum, etc. Some combine with oxygen with great energy; others form very unstable compounds with oxygen. Some form strong bases; others form weak bases.

4. *The Compounds of the Metals.*—These may be conveniently classified as:

a. Compounds with chlorine, bromine, and iodine; or the *chlorides*, *bromides*, and *iodides*.

b. Compounds with oxygen and with oxygen and hydrogen; or the *oxides* and *hydroxides*.

c. Compounds with sulphur and with sulphur and hydrogen; or the *sulphides* and *hydrosulphides*.

d. Compounds with nitric and nitrous acids; or the *nitrates* and *nitrites.*

e. Compounds with the acids of chlorine; or the *chlorates, chlorites,* etc.

f. Compounds with sulphuric and sulphurous acids; or the *sulphates* and *sulphites.*

g. Compounds with carbonic acid; or the *carbonates.*

h. Compounds with phosphoric acid; or the *phosphates.*

i. Compounds with silicic acid; or the *silicates.*

j. Compounds with boric acid; or the *borates.*

The acids of which the salts are derivatives are already known to you, and in dealing with the acids frequent reference has been made to the methods of making the salts, and to some of their most important properties. In what follows only those compounds will be treated of which well illustrate general principles, or which, owing to some familiar application, happen to be of special interest.

CHAPTER XIX.

THE POTASSIUM FAMILY: POTASSIUM, SODIUM (AMMONIUM).

Alkalies.—The members of this family are generally called *metals of the alkalies*, as the two best-known members are obtained from the alkalies, caustic potash and caustic soda, or potassium and sodium hydroxides.

Potassium, K (*At. Wt.* 39).—This element is a constituent of many minerals, particularly of *feld-spar*, which is a silicate of aluminium and potassium.

In the Soil.—The natural decomposition of minerals containing potassium gives rise to the presence of this element in various forms of combination everywhere in the soil, and it is of the highest importance for plants, as they use it as part of their food. When vegetable material is burned the potassium remains behind, chiefly as potassium carbonate. When wood-ashes are treated with water the potassium carbonate dissolves, and it is obtained in an impure state by evaporating the solution. The substance thus obtained is called *potash.*

EXPERIMENT 104.—Treat some wood-ashes with water. Filter off the solution, and examine it by means of red litmus-paper. Is the solution alkaline? Examine some potassium carbonate.— Does its solution act in the same way?—Evaporate to dryness the solution obtained from the wood-ashes. Collect the dry residue

and treat it in a test-tube with a little dilute hydrochloric acid. Is a gas given off ? Is it carbon dioxide ?

Potassium is also found in the form of the chloride KCl, accompanying the chloride of sodium, and as the nitrate in saltpetre.

How Potassium is Prepared.—The metal was first prepared by the action of a powerful electric current on caustic potash, which had been considered as an element. It is now manufactured by the action of an electric current on potassium hydroxide, cyanide, or chloride.

Properties.—It is a light substance that floats on water. Its freshly-cut surface has a bright metallic lustre, almost white; it acts upon water with great energy, causing the evolution of hydrogen, which burns, and the formation of potassium hydroxide. In consequence of its action on water, potassium cannot be kept in the air. It is kept under some oil upon which it does not act, as petroleum.

EXPERIMENT 105.—Throw a small piece of potassium not larger than a pea upon water. What takes place ? What is the color of the flame ? What difference is there between the action of sodium and of potassium on water ? Is the solution after the action alkaline ? Why ? See note, Exp. 35.

Compounds of Potassium.—The chief compounds of potassium are the *iodide*, KI; the *hydroxide*, or caustic potash, KOH; the *nitrate*, or saltpetre, KNO_3; the *chlorate*, $KClO_3$; and the *carbonate*, K_2CO_3.

Potassium Iodide, KI, is made by treating caustic potash with iodine. The action is the same as that which takes place when chlorine acts upon warm concentrated caustic potash. Both the iodide and iodate are formed:

$$6KOH + 6I = 5KI + KIO_3 + 3H_2O.$$

By evaporating off the water and heating the residue, the iodate is decomposed into iodide and oxygen.

EXPERIMENT 106.—Examine a bottle of crystallized potassium iodide. Taste a little. Dissolve some in water. Add some iodine to this solution. Does the iodine dissolve? Heat a little. Does the substance contain water of crystallization? Treat a crystal or two with a few drops of concentrated sulphuric acid. What takes place? To what is the appearance of violet vapors due? See Experiment 88.

Potassium iodide is extensively used in medicine and in photography.

Potassium Hydroxide, KOH.—This well-known sub-stance, commonly called caustic potash, is prepared by the action of an electric current on a concentrated solution of potassium chloride (see page 83):

$$2KCl + 2H_2O = 2KOH + H_2 + Cl_2.$$
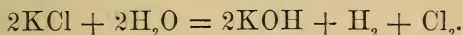
The hydroxide is a white brittle substance. In contact with the air it deliquesces [what does this mean?] and absorbs carbon dioxide. It is a strong base. [What products are formed when it acts upon hydrochloric acid? Upon nitric acid? Upon sulphuric acid? How many salts can it form with sulphuric acid? What are their formulas?]

Potassium Nitrate, KNO_3.—The common name of this salt is *saltpetre*. Its occurrence in nature has already been referred to. When refuse animal matter is left to undergo decomposition in the presence of bases, nitrates are formed.

Saltpetre Plantations.—Advantage is taken of the fact just mentioned for the purpose of preparing saltpetre artificially. Heaps of refuse matter from stables are

mixed with lime and kept moist, and then allowed to stand for a time. The nitrate which is formed is extracted with water, converted into potassium nitrate, and purified. Places where this process is carried on on the large scale are called *saltpetre plantations*.

Properties. — Potassium nitrate crystallizes in long rhombic prisms which have a salty taste. It is easily soluble in water.

Uses of Saltpetre.—It is used in making sulphuric acid [how?], and nitric acid [how?]. Its chief use is in the manufacture of gunpowder.

Gunpowder.—The value of gunpowder is due to the fact that it *explodes* readily, the explosion being a chemical change accompanied by a sudden evolution of gases. When the powder is enclosed in a gun-barrel the gases in escaping drive the ball before them. Gunpowder has long been known, and has always been made of *saltpetre, charcoal*, and *sulphur*. When heated the saltpetre gives off oxygen and nitrogen; the oxygen combines with the charcoal, forming carbon dioxide, and the sulphur combines with the potassium, forming potassium sulphide. The reactions are represented in this equation:

$$2KNO_3 + 3C + S = \underset{\text{Gas.}}{3CO_2} + \underset{\text{Gas.}}{2N} + \underset{\text{Solid.}}{K_2S.}$$
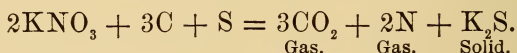
EXPERIMENT 107.—Mix together 15 grams potassium nitrate and 2.5 grams powdered charcoal. Set fire to the mass.

Potassium Chlorate, $KClO_3$, has so frequently been referred to and used in earlier experiments that it is not necessary to say anything more about it now.

Sodium, Na (*At. Wt.* 23).—Sodium occurs very widely distributed and in large quantities, principally as sodium

chloride. It occurs also as sodium nitrate, and as the silicate in many minerals. Like potassium it is found everywhere in the soil, and is taken up by plants, especially by those which grow in the neighborhood of the sea and in the sea.

Preparation of Sodium.—Sodium is made by the same method as that used for making potassium.

Properties.—Its properties are very similar to those of potassium. It is light, floating on water, it has a bright metallic lustre, and is soft, like wax. It decomposes water, but not as actively as potassium.

Sodium a Strong Reducing Agent.—Sodium has a strong attraction for oxygen, and is used in some chemical processes as a reducing agent, as, for example, in the preparation of aluminium. A compound of mercury and sodium, known as sodium amalgam, is used in some metallurgical operations connected with the extraction of gold and silver from their ores.

Compounds of Sodium.—The chief compounds of sodium are the *chloride*, $NaCl$; the *hydroxide*, or caustic soda, $NaOH$; the *nitrate*, or Chili saltpetre, $NaNO_3$; the *sulphate*, Na_2SO_4; the *carbonate*, Na_2CO_3; and the *borate*, or borax, $Na_2B_4O_7$.

Sodium Chloride, $NaCl$.—This is the substance known by the name *common salt*. It occurs very widely distributed, and, as it is easily soluble, much of the water which enters into the ocean contains some of it in solution. Sea-water contains $2\frac{1}{2}$ to 3 per cent of sodium chloride.

How Salt is Obtained.—In some places salt is taken out of mines in the solid form; in others water is allowed to

flow into the mines, and to remain for some time in contact with the salt, and the solution thus formed is drawn or pumped out of the mine and evaporated by appropriate methods. Salt is also obtained from the sea in hot countries. At high tide the water is dammed up, and the artificial ponds thus formed afterwards evaporate under the influence of the sun, leaving the salt behind.

Properties.—Sodium chloride crystallizes in colorless and transparent cubes. Its taste is familiar to every one.

Uses of Salt.—Salt is an extremely important article of food. It is necessary to the life of man as well as of many animals. It is found in all parts of the body. It is used to prevent decomposition of meats. Salt pork and salt fish are familiar to all. Salt is used as the starting-point in the preparation of all sodium compounds and of all chlorine compounds.

[How are chlorine and hydrochloric acid obtained from it ?]

Sodium Hydroxide, $NaOH$.—This is commonly called caustic soda. It can be prepared in the same way as potassium hydroxide. Its properties are very similar to those of caustic potash.

Sodium Nitrate, $NaNO_3$.—This is the salt which has been repeatedly referred to by the name of Chili saltpetre. It occurs in very large quantities, and is the chief source of nitric acid. It is cheaper than potassium nitrate, but cannot be substituted for it in the manufacture of gunpowder, because it becomes moist in the air. It is converted into potassium nitrate by treating its solution with potassium chloride:

$$NaNO_3 + KCl = KNO_3 + NaCl.$$
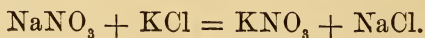
The potassium nitrate is separated from the sodium chloride by crystallization.

Sodium Sulphate, $Na_2SO_4 + 10H_2O$.—The common name of this substance is Glauber's salt. It is manufactured in large quantities by treating sodium chloride with sulphuric acid:

$$2NaCl + H_2SO_4 = 2HCl + Na_2SO_4;$$
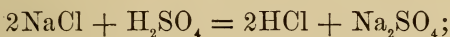
and by the action of magnesium sulphate on sodium chloride:

$$2NaCl + MgSO_4 = Na_2SO_4 + MgCl_2.$$
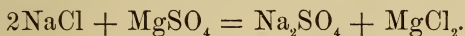
It crystallizes in large, colorless, monoclinic prisms, containing 10 molecules of water of crystallization, $Na_2SO_4 + 10H_2O$. It loses water when left in contact with the air.

It is extensively used in the manufacture of glass.

Sodium Carbonate, $Na_2CO_3 + 10H_2O$.—This salt, commonly called *soda*, is one of the most important of manufactured chemical substances. The mere mention of the fact that it is essential to the manufacture of glass and soap will give an idea of its importance. It is found in the ashes of sea-plants, just as potassium carbonate is found in the ashes of land-plants. Formerly it was obtained from this source. Now, however, we are not dependent upon sea-plants for our supply, as two methods have been devised for preparing it from sodium chloride, with which the earth is so abundantly supplied.

Manufacture of Soda from Sodium Chloride.—During the French Revolution the supply of soda was cut off from France, and the government therefore offered a large prize

for a method of making it from common salt. A method was devised by Leblanc which has been used very extensively ever since.

Leblanc's Method for Making Soda.—This depends upon four reactions:

1st. The sodium chloride is converted into sodium sulphate by treating it with sulphuric acid:

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl.$$
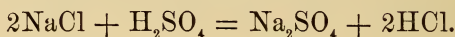
2d. The sodium sulphate thus obtained is heated with charcoal, which reduces it to sodium sulphide, Na_2S:

$$Na_2SO_4 + 4C = Na_2S + 4CO.$$
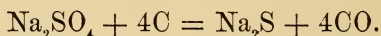
3d. The sodium sulphide is heated with calcium carbonate, when sodium carbonate and calcium sulphide are formed:

$$Na_2S + CaCO_3 = Na_2CO_3 + CaS.$$
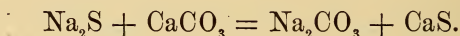
4th. If lime is present in the last reaction, it forms an insoluble compound with calcium sulphide. By treating the product of the reaction with water the sodium carbonate alone dissolves.

In practice the sodium sulphate is mixed with charcoal and calcium carbonate and the mixture heated.

The Solvay or Ammonia Method.—Another method has recently come into great prominence, threatening to drive out the Leblanc method completely. This is the Solvay, or the ammonia, method. This depends upon the fact that the salt, $HNaCO_3$, is comparatively difficultly soluble in water and is therefore precipitated from a solution of common salt by the addition of the easily soluble acid ammonium carbonate.

Properties.—Sodium carbonate crystallizes in large prisms with 10 molecules of water of crystallization. The crystals are efflorescent.

Mono-sodium Carbonate, $HNaCO_3$, or *bicarbonate of soda*, is made from sodium carbonate by passing carbon dioxide into it:

$$Na_2CO_3 + CO_2 + H_2O = 2HNaCO_3.$$
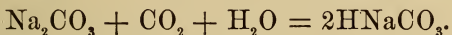
This substance is one of the constituents of *baking-powders* which are used for raising bread. *Seidlitz powders* consist of the bicarbonate and cream of tartar mixed together. When water is added to the mixture, carbon dioxide is given off, as the cream of tartar is an acid salt, acid potassium tartrate, $KHC_4H_4O_6$, and *Rochelle salt* is left in solution. This is the potassium and sodium salt of tartaric acid, of the composition $KNaC_4H_4O_6$.

Disodium Phosphate, $Na_2HPO_4 + 12H_2O$.—This is the common form of sodium phosphate.

Sodium Borate, Borax, $Na_2B_4O_7 + 10H_2O$.—This salt is found in several lakes in Asia, and in this country in Clear Lake, Nevada. It is also manufactured by neutralizing the boric acid found in Tuscany. When heated, borax puffs up, and at red heat melts, forming a transparent, colorless liquid. This is the dry substance, $Na_2B_4O_7$. Molten borax has the power to dissolve the oxides of the metals, and forms colored glasses with some of them. In *soldering* it is necessary that the metals should be clean and bright. To secure this a little molten borax is put on the surfaces which are to be united. Borax is an *antiseptic;* that is to say, it prevents the decomposition of organic substances.

Water-glass.—Silicon dioxide, or silica, SiO_2, dissolves by continued boiling with caustic soda or potash, and sodium or potassium silicate is thus formed:

$$SiO_2 + 2NaOH = Na_2SiO_3 + H_2O.$$

These salts are soluble in water, and are known as water-glass. Water-glass is used in making artificial stone, and for the purpose of protecting certain stones from the action of the weather.

Ammonium Salts.—When the gas ammonia, NH_3, or its solution in water, is brought together with acids, salts are formed. Thus ammonia and hydrochloric acid give a salt of the composition NH_4Cl; ammonia and nitric acid give NH_4NO_3; ammonia and sulphuric acid give $(NH_4)_2SO_4$. The salts are formed according to the following equations:

$$NH_3 + HCl = NH_4Cl;$$
$$NH_3 + HNO_3 = NH_4NO_3;$$
$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4.$$
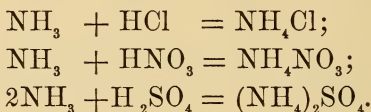
The salts thus formed are much like the salts of sodium and potassium. They can be understood best by assuming that in them the part represented by NH_4 acts the part of the metal in metallic salts.

It is called ammonium, and the salts are called *ammonium* salts. Ammonium has never been obtained in the uncombined state, as instead of it ammonia and hydrogen are always formed.

EXPERIMENT 108.—Place near each other two vessels, one containing a little strong hydrochloric acid, and the other a little strong ammonia. Explain what you see.

Ammonium Chloride, NH_4Cl.—This salt is sometimes called *sal-ammoniac.* When heated it is converted into

vapor without melting, and with very slight decomposition.

EXPERIMENT 109.—On a piece of platinum-foil or porcelain heat a little ammonium chloride. What is the result?

[What takes place when ammonium chloride is treated with caustic soda? With lime?]

Ammonium Sulphide, $(NH_4)_2S$.—This salt, which is made by treating ammonia with hydrogen sulphide, is extensively used in making chemical analyses.

Relations between the Atomic Weights of the Alkali Metals.—The atomic weight of *lithium*, which is a metal belonging to the potassium family, is 7. Between this and the atomic weights of sodium, 23, and potassium, 39, exist relations similar to those which exist between the atomic weights of chlorine, bromine, and iodine; and of sulphur, selenium, and tellurium. [What is this relation?]

Flame Reactions.—When a piece of clean platinum wire is held for some time in the flame of the Bunsen burner, it then imparts no color to the flame. If now a small piece of sodium carbonate or any other salt of sodium be put on it, the flame is colored intensely yellow. All sodium compounds have this power, and hence the chemist makes use of the fact for the purpose of detecting the presence of sodium. Similarly, potassium compounds color the flame violet.

EXPERIMENT 110.—Prepare some pieces of platinum wire, 8 to 10 cm. long, with a small loop on the end. After thoroughly cleaning them, insert one in a little sodium carbonate, and notice the color it gives to the flame. Try another with potassium carbonate.

To Separate Two or More Colors.—While it is an easy matter to recognize potassium alone, or sodium alone, it is not so easy to do so when they are together in the same compound. The intense yellow caused by the sodium completely masks the more delicate violet caused by the potassium, so that the latter cannot be seen by the unaided eye. In this particular case we can get over the difficulty by letting the light pass through a blue glass, or a thin vessel filled with a solution of indigo. The yellow light is thus cut off, while the violet light passes through and can be recognized.

The Prism and the Spectrum.—A better method for detecting what a light consists of is by means of a prism. Lights of different colors are turned out of their course to different extents when passed through a prism, as is seen in the case of sunlight. A narrow beam of white light passing in emerges as a band of various colors, called its *spectrum*. It is thus seen that white light is made of different-colored lights. Similarly, we can determine what any light is composed of. Every light has its characteristic spectrum. The light produced by burning sodium, or by introducing a sodium compound in a colorless flame, has a spectrum consisting of a narrow yellow line or two lines very near together. The spectrum of potassium consists mainly of two lines, one red and one violet. Further, these lines always occupy definite positions relatively to one another, so that, in looking through a prism at the light caused by potassium and sodium, the yellow line of sodium is seen in its position, and the two potassium lines in their positions.

The Spectroscope. — The instrument used for the purpose of examining the spectra of different lights is called the *spectroscope*. It consists essentially of a prism and two tubes. Through one of the tubes a narrow beam of the light to be examined is allowed to pass so as to strike on the prism. The light emerges from the other side of the prism, and is observed through the other tube, which is provided with lenses for the purpose of magnifying the spectrum. By means of the spectroscope it is possible to detect the minutest quantities of some elements, and, since it was devised, several new elements have been discovered through its aid, as, for example, cæsium, rubidium, thallium, indium, and gallium.

Discovery of Helium by the Aid of the Spectroscope.—An interesting case of the use of the spectroscope is that of helium. A certain yellow line is characteristic in the spectrum of this element. It was first observed in the solar chromosphere and protuberances. More than twenty-five years later it was found in the gases given off from certain rare minerals. It has since been studied with some care. Its atomic weight is 4.

CHAPTER XX.

THE CALCIUM FAMILY: CALCIUM, BARIUM, STRONTIUM.

Calcium, Ca (*At. Wt.* 40).—This is the principal member of the family. It is widely distributed in nature and in enormous quantities; principally as carbonate, $CaCO_3$, in the form of limestone, marble, and chalk; as sulphate, $CaSO_4$, in the form of gypsum; as phosphate, $Ca_3(PO_4)_2$, in phosphorite and apatite; as fluoride, CaF_2, in fluor spar.

The element is not easily made. It acts upon water just as sodium and potassium do.

Compounds of Calcium.—The principal compounds of calcium with which we have to deal are the *chloride*, $CaCl_2$; the *oxide*, or quicklime, CaO; the *hydroxide*, or slaked lime, $Ca(OH)_2$; the *carbide*, CaC_2; the *hypochlorite*, $Ca(OCl)_2$; the *carbonate*, $CaCO_3$; the *sulphate*, $CaSO_4$; the *phosphate*, $Ca_3(PO_4)_2$; and the *silicates*, in the form of glass.

Calcium Chloride, $CaCl_2$.—The property which gives this salt its value is its power to absorb water. It is used as a drying agent. Gases are passed through it for the purpose of drying them, and it is also placed in vessels in which it is necessary that the atmosphere should be kept dry.

EXPERIMENT 111.—Dissolve 10 to 20 grams of limestone or marble in ordinary hydrochloric acid. Evaporate to dryness. Expose a few pieces of the residue to the air.—Does it become moist? In what experiments has calcium chloride been used, and for what purposes? What would happen if sulphuric acid were added to calcium chloride? Try it. Explain what takes place. Is the residue soluble or insoluble in water?

Calcium Oxide, CaO.—This is the substance commonly called *lime*. It is made by heating calcium carbonate, which is decomposed into lime and carbon dioxide:

$$CaCO_3 = CaO + CO_2.$$

Limekilns are large furnaces in which limestone and other forms of calcium carbonate are heated and converted into lime.

Lime is a white substance which does not melt except in the electric furnace. When heated in the flame of the oxyhydrogen blowpipe, it gives forth an intense light, as any other infusible substance would under the same circumstances. When exposed to the air, it attracts moisture and carbon dioxide and is thus converted into the carbonate. This change is called *air-slaking*, and lime thus changed is said to be *air-slaked*.

Calcium Hydroxide, $Ca(OH)_2$.—When calcium oxide or quicklime is treated with water it becomes hot and crumbles to a fine powder. The substance which is formed in this operation is somewhat soluble in water, the solution being known as *lime-water*.

Slaking.—The action that takes place when lime is treated with water is called *slaking*. It is represented by the equation

$$CaO + H_2O = Ca(OH)_2.$$
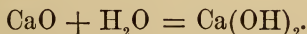
The oxide is converted into the hydroxide or hydrate.

EXPERIMENT 112.—To 40 or 50 grams good quicklime add 100 c.c. water. What takes place? Afterwards dilute to 2 to 3 litres and put the whole in a wide-stoppered bottle. The undissolved lime will settle to the bottom, and in the course of some hours the solution above will become clear. Carefully pour off some of the clear solution. What takes place when some of the solution is exposed to the air? When the gases from the lungs are passed through it? When carbon dioxide is passed through it? What takes place when dilute sulphuric acid is added to lime-water? Is calcium sulphate difficultly or easily soluble in water? Has lime-water an alkaline reaction? What reaction would you expect to take place between lime and nitric acid?

Calcium Carbide, CaC_2.—This compound is easily formed by heating lime and coke together in the form of powder in an electric furnace, when the reaction represented below takes place:

$$CaO + 3C = CaC_2 + CO.$$
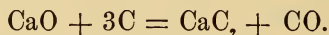
It is a crystallized substance. With water it gives acetylene and lime. (See Acetylene.)

Calcium Hypochlorite, $Ca(OCl)_2$, has already been treated of sufficiently under the head of Chlorine. It need only be repeated that the form in which chlorine is transported is "*bleaching-powder*" or "*chloride of lime.*" This is a compound containing calcium hypochlorite and calcium chloride, $Ca(OCl)_2 + CaCl_2$, which is made by passing chlorine into slaked lime:

$$2Ca(OH)_2 + 4Cl = \underbrace{Ca(OCl)_2 + CaCl_2}_{\text{Bleaching-powder.}} + 2H_2O.$$
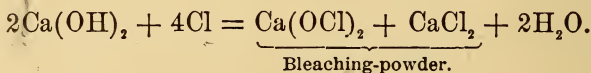
How Bleaching-powder Gives up Chlorine.—Bleaching-powder gives up its chlorine by simple exposure to the air in consequence of the action of the carbon dioxide. The addition of an acid causes a rapid evolution of chlorine.

Calcium Carbonate, $CaCO_3$.—This salt occurs in nature in the well-known forms calc-spar, limestone, marble, and chalk. The variety of calc-spar found in Iceland, and known as Iceland spar, is particularly pure calcium carbonate. The salt also forms the principal part of oyster-shells, coral, etc. In some caves water containing calcium carbonate in solution drips down, and the salt is deposited in the solid form from the solution because the excess of carbon dioxide that holds the carbonate in solution is given off (see page 128). Thus hanging pieces, shaped like icicles are formed, and below them reaching up from the bottom are similar pieces with the pointed ends upwards. Those which hang down from above are called *stalactites ;* those on the bottom are called *stalagmites*.

Calcium Sulphate, Gypsum, $CaSO_4 + 2H_2O$.—Gypsum is the principal variety of calcium sulphate. When heated it loses part of its water of crystallization and forms a powder called *plaster of Paris*, which has the power of taking up water and forming a solid substance. The process of solidification is known as "setting." Plaster of Paris is largely used in making casts.

EXPERIMENT 113.—Heat some powdered gypsum to about 180° in an air-bath. Examine what is left and see whether it will become solid when mixed with a little water so as to form a paste. See whether gypsum itself will act in the same way.

Permanent Hardness of Water.—Calcium sulphate is somewhat soluble in water. A natural water containing either gypsum or calcium carbonate is called a *hard water*. The hardness caused by calcium carbonate is remedied by boiling the water, and is, therefore, called *temporary*

hardness, while that which is caused by gypsum is not remedied by boiling and is therefore called *permanent hardness*. Why the water is called hard will be explained when the subject of soap is treated.

How to Improve Hard Water.—Water that holds calcium carbonate in solution can be made soft by adding a little lime to it. This forms insoluble calcium carbonate with the carbon dioxide, and, as soon as the carbon dioxide is removed, the calcium carbonate in solution is precipitated. If the hardness is caused by calcium sulphate the addition of a little carbonate of soda will precipitate the calcium as calcium carbonate, and sodium sulphate will be left in solution:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$
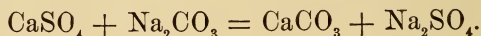
[Try these reactions.]

Gypsum Valuable as a Fertilizer.—The addition of gypsum to a soil increases its fertility, and it is therefore frequently used by farmers to increase their crops.

Calcium Phosphate, $Ca_3(PO_4)_2$.—The normal phosphate in which calcium is substituted for all the hydrogen of phosphoric acid is found in nature as phosphorite, and in combination with calcium fluoride or chloride as apatite. Further, it is the chief earthy constituent of bones, and is found in large quantity in bone-ash.

Calcium Phosphate as a Fertilizer.—Plants need phosphoric acid for their growth, and hence it must be present in the soil if the plants are to flourish. Ordinary normal calcium phosphate is not soluble, and is therefore not easily taken up by the plants. It can be rendered soluble by adding sulphuric acid to it, and then it is readily used by the plants.

Superphosphate of Lime.—Normal calcium phosphate that has been treated with a certain proportion of sulphuric acid forms the valuable artificial fertilizer known as *superphosphate of lime.* This is a mixture of the phosphate $Ca(H_2PO_4)_2$ and calcium sulphate formed thus:

$$Ca_3(PO_4)_2 + 2H_2SO_4 = \underbrace{2CaSO_4 + Ca(H_2PO_4)_2.}_{\text{Superphosphate of lime.}}$$
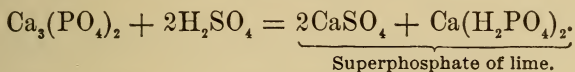
Mortar.—Mortar is made of slaked lime and sand. When this mixture is exposed to the air, calcium carbonate is slowly formed, and the mass becomes extremely hard. The water contained in the mortar soon passes off, but nevertheless freshly-plastered rooms remain moist for a considerable length of time. This is due to the fact that a reaction continues to take place between the carbon dioxide and calcium hydroxide in which calcium carbonate and water are formed,

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O,$$
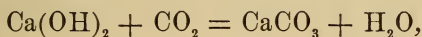
and it is the water thus set free which keeps the air moist. The complete conversion of the lime into carbonate requires a long time, because the carbonate that is formed on the surface tends to protect the lime in the interior. The hardening can be hastened by keeping up fires of coke or charcoal and allowing the products of combustion to escape into the rooms.

Glass.—*Common glass* is a silicate of calcium and sodium, made by melting together sand (silicon dioxide, SiO_2) with lime, or calcium carbonate, and sodium carbonate. When potassium carbonate is used instead of sodium carbonate the glass is more difficultly fusible.

Bohemian glass, which is so extensively used in the manufacture of chemical apparatus, is a silicate of calcium and potassium. *Flint-glass*, which is especially valuable for the manufacture of optical instruments, contains lead instead of calcium. It melts much more readily than calcium glass.

Colored Glass.—Colors are given to glass by putting in the fused mass small quantities of various substances. Thus a cobalt compound makes glass blue; copper and chromium make it green; one of the oxides of copper makes it red, etc.

Compounds of Barium and Strontium.—These closely resemble those of calcium. Barium forms an oxide, BaO, corresponding to lime, and also another one known as barium dioxide, BaO_2. This is formed by passing oxygen or air over barium oxide heated to a dull red heat. At a higher temperature it gives off the oxygen. These facts are taken advantage of for the purpose of *extracting oxygen from the air*.

Barium Dioxide Used in Making Hydrogen Dioxide.—Barium dioxide has already been referred to in describing the preparation of hydrogen dioxide, H_2O_2. When it is treated with sulphuric acid this reaction takes place:

$$BaO_2 + H_2SO_4 = H_2O_2 + BaSO_4.$$
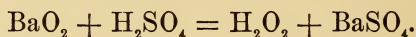
When it is treated with hydrochloric acid hydrogen dioxide is also formed, thus:

$$BaO_2 + 2HCl = H_2O_2 + BaCl_2.$$
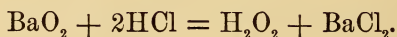
[Compare this with the reaction which takes place when hydrochloric acid acts upon manganese dioxide.]

Flame Reactions.—Calcium compounds color the flame reddish-yellow; strontium compounds, intense red; and barium compounds, yellowish-green. They are frequently used for the purpose of producing colored lights.

Relations between the Atomic Weights.—The atomic weight of calcium is 40, that of strontium 87.5, and that of barium 137. [Why is this fact of special interest?]

CHAPTER XXI.

THE MAGNESIUM FAMILY: MAGNESIUM, ZINC, CADMIUM.

THE COPPER FAMILY: COPPER, MERCURY, SILVER.

Magnesium, Mg (*At. Wt.* 24).—Magnesium occurs very widely distributed in nature, and in considerable quantities. Among the important magnesium minerals are *magnesite*, which is the carbonate, $MgCO_3$; *dolomite*, a carbonate of magnesium and calcium; *soapstone, serpentine*, and *meerschaum*, which are essentially silicates of magnesium. Further, there are many well-known minerals that contain magnesium, as *asbestos* and *hornblende*. The element is also found in solution in many spring-waters in the form of the sulphate, which is known as Epsom salt.

Preparation of Magnesium.—It is prepared by electrolysis of dehydrated carnallite, $KMgCl_3$. This is melted in an iron crucible. One pole of the battery is a piece of carbon, the other is the crucible itself.

Properties.—It is a silver-white metal with a high lustre. In the air it changes slowly, but it gradually becomes covered with a layer of the oxide. It burns with a bright flame, forming the white oxide and some nitride, Mg_3N_2.

At ordinary temperatures magnesium does not decompose water; at 100° it decomposes it slowly. [Compare magnesium with potassium and sodium in this respect.]

Magnesium Oxide, MgO.—This compound is commonly called *magnesia*. A fine white variety is made by heating precipitated magnesium carbonate; this is called *magnesia usta*. It is very difficultly soluble in water, forming with it magnesium hydroxide, $Mg(OH)_2$, which is practically insoluble in water. [What difference is there between magnesium and calcium in this respect?]

Zinc, Zn (*At. Wt.* 65).—Zinc occurs in nature in combination as the *carbonate*, or *calamine*, $ZnCO_3$, as the *silicate*, and as the *sulphide*, or *zinc blende*, ZnS.

Preparation of Zinc.—It is prepared by mixing the oxide with charcoal and heating in earthenware retorts. The metal, being volatile, passes over and is condensed.

Properties of Zinc.—Zinc has very different properties at different temperatures. At ordinary temperatures it is quite brittle; at 100–150° it can be rolled out in sheets, but above 200° it becomes brittle again. In dry air it does not change. When heated in the air it takes fire, and burns with a bluish flame, forming zinc oxide. It dissolves in all the common acids, usually with an escape of hydrogen.

Uses.—It is used very largely in making batteries. Iron covered with a layer of zinc is known as *galvanized iron*. Zinc plates covered with a layer of zinc amalgam, formed by applying mercury, are used in galvanic batteries. Zinc is one of the constituents of *brass*, the other being copper. *German silver* consists of brass to which some nickel has been added.

Zinc Oxide, ZnO, is obtained as *Flores zinci* by burning zinc, and by heating the carbonate or nitrate of zinc. It turns yellow when heated, but becomes white again on cooling.

EXPERIMENT 114.—In a furnace, or in a hot stove fire, heat a small sand crucible to a bright red heat. Throw into it pieces of zinc. If the temperature is high enough the zinc will boil and the vapor will burn with a bright light, and dense white fumes of the oxide will be formed.—Heat a small piece of zinc or charcoal in the oxidizing flame of the blowpipe. The white fumes of zinc oxide (*philosopher's wool*) will be seen, and the charcoal will be covered with a film that is yellow while hot, but becomes white on cooling.

Zinc oxide is used as a constituent of paint under the name *zinc-white*. White lead turns black quite readily. Zinc-white does not.

Zinc Sulphate, $ZnSO_4 + 7H_2O$.—The common name of this salt is *white vitriol*. It is obtained on the large scale by heating zinc sulphide in contact with the air. Under these circumstances the sulphide is oxidized:

$$ZnS + 4O = ZnSO_4.$$
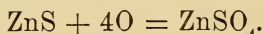
This operation is known as *roasting*. By roasting zinc sulphide at a higher temperature it is converted into zinc oxide:

$$ZnS + 3O = ZnO + SO_2.$$
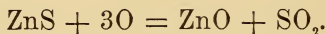
Zinc sulphate is also formed in large quantities in galvanic batteries and in the preparation of hydrogen.

Copper, Cu (*At. Wt.* 63.1).—Copper occurs in nature in the uncombined or native state in large quantities in the neighborhood of Lake Superior, United States, and in Chili. It also occurs in combination with oxygen as *ruby copper*, which is the oxide, Cu_2O; and with sulphur and iron in *copper pyrites*, $CuFeS_2$.

Preparation of Copper.—Copper is obtained from the oxide by heating it with charcoal. [This reduction has been illustrated under the head of carbon (see Experiment 70)]. It is also obtained from the sulphides. The chemical changes involved are comparatively complicated. It is also made electrolytically.

Properties.—Copper is a hard metal of a reddish color and metallic lustre. In dry air it does not change, but in moist air it gradually becomes covered with a green layer of a carbonate of copper. Nitric acid dissolves it, copper nitrate, $Cu(NO_3)_2$, being formed, and oxides of nitrogen evolved [explain the reaction]; hydrochloric acid does not act upon it; sulphuric acid acts when heated with the metal; the sulphate, $CuSO_4$, is formed and sulphur dioxide given off. Copper does not decompose water, even when water vapor is passed over the metal heated to redness. [Compare with the conduct of the members of the potassium, calcium, and magnesium families.

Copper-plating.—Copper is precipitated from solutions of its salts by zinc, iron, and some other metals, and by an electric current.

EXPERIMENT 115.—Into a neutral solution of copper sulphate insert a bright strip of zinc. The zinc will become covered with a layer of copper, and zinc will pass into solution as zinc sulphate. The zinc displaces the copper in this case, as it displaces hydrogen from sulphuric acid :

$$Zn + CuSO_4 = ZnSO_4 + Cu;$$
$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$
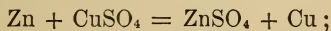
Perform a similar experiment, using a bright strip of sheet-iron instead of zinc. [What is the result?]

The deposition of metallic copper from solutions of its salts is extensively used in *copper-plating*. The object to be covered with copper is hung in a solution of copper

sulphate and connected with one pole of a galvanic battery, the other pole being also in the solution. Decomposition takes place, and a layer of copper is deposited on the object.

Alloys of Copper.—Mixtures of metals made by melting them together are called *alloys*. *Brass* is an alloy consisting of about 1 part of zinc and 2 parts of copper. *Bell-metal* and *bronze* are alloys of copper and tin.

Copper Forms Two Series of Salts.—Copper has the power to form two distinct series of compounds, of which the following are examples:

$$CuCl, \quad CuCl_2;$$
$$CuBr, \quad CuBr_2;$$
$$Cu_2O, \quad CuO.$$
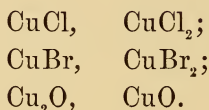
Those which belong to the first class, corresponding to the chloride, $CuCl$, are called *cuprous compounds*. Thus, $CuCl$ is *cuprous chloride;* Cu_2O, *cuprous oxide*, etc. On the other hand, compounds of the second class are called *cupric compounds*. Thus, $CuCl_2$ is *cupric chloride;* CuO, *cupric oxide*, etc. Mercury, iron, and some other metals also form two series of compounds which differ from each other in much the same way.

Cuprous Oxide, Cu_2O, is found in nature as *ruby copper*, and is formed when copper is heated in contact with the air. It is a bright-red, compound insoluble in water.

Cupric Oxide, CuO, is obtained by heating copper to redness in contact with the air, or by heating the nitrate. It is also formed when caustic soda or potash is added to a boiling-hot solution of a copper salt. If the solution is cold, blue *cupric hydroxide*, $Cu(OH)_2$, is precipitated, but

this easily loses water, and is converted into the oxide, CuO, which is black, particularly if the solution is heated. The reactions which take place are:

$$CuSO_4 + 2NaOH = Cu(OH)_2 + Na_2SO_4, \text{ and}$$
$$Cu(OH)_2 = CuO + H_2O.$$
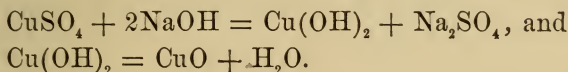
EXPERIMENT 116.—Add a dilute solution of caustic soda or potash to a small quantity of a dilute cold solution of copper sulphate in a test-tube. After noticing the appearance of the precipitate first formed, heat. What change takes place ?—Add caustic soda in the same way to a hot solution of copper sulphate.

Copper Sulphate, $CuSO_4 + 5H_2O$. This salt is manufactured on a large scale, and is commonly known by the name "blue vitriol." [What salt is called "white vitriol"?] It forms large blue crystals, which, when heated, lose water and become colorless. The colorless substance becomes blue again in contact with water. It is used in galvanic batteries, in copper-plating, and as a remedy for the pest of grape-vines, *phylloxera*.

Mercury, Hg (*At. Wt.* 200).—Mercury occurs in the uncombined state as drops enclosed in rocks, though principally in combination with sulphur as *cinnabar*, HgS. It is obtained by roasting cinnabar, when vapors of mercury and sulphur dioxide are given off. The mercury is then condensed in appropriate vessels. It is a silver-white metal of a high lustre. At ordinary temperatures it is liquid, though it becomes solid at − 39°.5. It does not change in the air at ordinary temperatures. It is insoluble in hydrochloric acid and cold sulphuric acid. [Try each.] It dissolves in hot concentrated sulphuric acid, and is easily soluble in nitric acid. [Try each.] The vapor of mercury is very poisonous.

Amalgams.—With other metals mercury forms alloys called *amalgams*. In ordinary galvanic batteries the zinc plates are treated with mercury, and thus covered with a layer of zinc amalgam which protects them from the action of the acids used.

Mercuric Oxide, HgO, is the red substance that was used in one of the first experiments for the purpose of preparing oxygen. It is formed when mercury is heated for some time near its boiling-point in contact with the air, and is made by heating the nitrate.

Mercurous Chloride, HgCl, is commonly known by the name *calomel*. It is precipitated when a soluble chloride or hydrochloric acid is added to a solution of any mercurous salt. It is manufactured by subliming an intimate mixture of mercuric chloride and mercury:

$$HgCl_2 + Hg = 2HgCl.$$
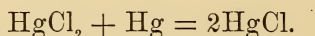
It is a white substance, insoluble in water, which finds extensive application in medicine.

Mercuric Chloride, $HgCl_2$, commonly called *corrosive sublimate*, is manufactured on the large scale by subliming an intimate mixture of mercuric sulphate and common salt:

$$HgSO_4 + 2NaCl = Na_2SO_4 + HgCl_2.$$
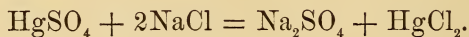
It is a white substance, soluble in water. It is extremely poisonous, and prevents the decay of organic substances. It is used as an antiseptic in surgery.

Silver, Ag (*At. Wt.* 107).—Silver occurs in the uncombined state or native; in combination with sulphur; and with sulphur and other metals. Small quantities of silver sulphide are found in almost all varieties of galenite or lead

sulphide. It occurs more rarely as the chloride, bromide, and iodide.

Extraction of Silver from its Ores.—Much of the silver used is obtained from galenite. This mineral is treated so as to effect the separation of the lead (see Lead), and the silver is separated from sulphur at the same time. But it is dissolved in a large quantity of lead, and the problem which presents itself to the metallurgist is how to separate the small quantity of silver from the large quantity of lead.

Pattinson's Process.—The separation of the silver from the lead is accomplished by a process invented by Pattinson. It consists in melting the mixture and allowing it to cool until crystals appear. These are nearly pure lead. They are dipped out and the liquid left is again treated in the same way. By this means there is finally obtained a product which is rich in silver, but which still contains some lead. This is heated in appropriate vessels in contact with the air, when the lead is oxidized, while the silver remains in the metallic state. This last process is called *cupellation.* This process has been superseded by the

Zinc Method, or Parker's Method.—This consists in treating the molten alloy with zinc, which takes up all the silver. The alloy of zinc and silver thus formed is removed, and afterwards treated with superheated steam, by which the zinc is oxidized and the silver left unchanged.

Amalgamation Process.—Some ores of silver are treated in another way, known as the *amalgamation process.* The ores are mixed with common salt and roasted, when the

silver is obtained in the form of the chloride. The mass is then treated with iron and water, when this reaction takes place:

$$2AgCl + Fe = FeCl_2 + 2Ag.$$
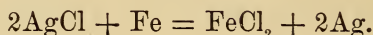
The mass is next treated with mercury, which forms an amalgam with the silver. When this amalgam is taken out, dried and heated, the mercury passes over, while the silver remains behind.

Properties of Silver.—Silver is a white metal with a high lustre. It is not acted upon by air, oxygen, or water at ordinary temperatures. Sulphur acts readily upon it, causing it to blacken superficially, the black coating being silver sulphide. Silver coins and other articles carried in the pockets are apt to become tarnished in consequence of the presence of small quantities of sulphur in the perspiration.

Alloys of Silver.—The silver which is used for coins and most other purposes is an alloy with copper, the pure metal being too soft. The alloy usually contains from $7\frac{1}{2}$ to 10 per cent of copper.

Silver-plating.—Objects are covered with silver mostly by connecting them with one pole of an electric battery and placing them in a bath containing a silver salt in solution, in which the other pole of the battery is also inserted. Glass is covered with silver by putting it into a solution containing silver together with something which has the power to separate the silver in the metallic state when heated. Under these circumstances the silver is deposited in a smooth, lustrous layer. Mirrors are made in this way.

Silver Nitrate, $AgNO_3$, is also called "lunar caustic," as it has the power to destroy the flesh, and is therefore used to burn out wounds. It is prepared by dissolving silver in dilute nitric acid. Marks made by silver nitrate turn black in the sunlight. Hence this salt is used as a constituent of *indelible inks*. When working with silver salts the fingers are apt to become stained. These stains and generally any spots made by silver salts can be removed by a solution of potassium cyanide, which forms soluble salts with compounds of silver.*

EXPERIMENT 117.—Dissolve a ten or twenty-five cent piece in dilute nitric acid. What action takes place? Dilute the solution to 200 to 300 c.c. with water. What is the color of the solution? What does this indicate? Does this color prove that copper is present? Add a solution of common salt until it ceases to produce a precipitate. The chemical change that takes place is expressed by the equation

$$AgNO_3 + NaCl = AgCl + NaNO_3.$$
Insoluble.
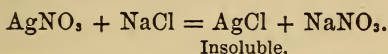
The copper nitrate is not changed and remains in solution. Filter off the white silver chloride and carefully wash with hot water. Dry the precipitate on the filter, by placing the funnel with the filter and precipitate in an air-bath heated to about 110°. Remove the precipitate from the filter and put it into a porcelain crucible. Heat gently with a small flame until the chloride is melted. Cut out a piece of sheet-zinc large enough to cover the silver chloride. Lay it on the silver chloride. Now add a little water and a few drops of dilute sulphuric acid, and let the whole stand for twenty-four hours. The silver chloride is changed to silver, and zinc chloride is formed:

$$Zn + 2AgCl = ZnCl_2 + 2Ag.$$
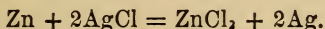
* Some years ago a scoundrel disfigured the beautiful marble statue of the great chemist Liebig which is in Munich by bespattering it with a solution of nitrate of silver. The professors of chemistry in the university succeeded, however, in removing the stains completely by applying a paste containing potassium cyanide.

Take out the piece of zinc and wash the silver with a little dilute sulphuric acid, and then with water. Dissolve the silver in dilute nitric acid and evaporate to dryness on the water-bath, so that the excess of nitric acid is driven off. Dissolve the residue in water, and put the solution either in a bottle of dark glass or one wrapped in dark paper.

EXPERIMENT 118.—To a few cubic centimetres of water in a test-tube add 5 to 10 drops of the solution of silver nitrate just prepared. To this dilute solution add a little of a dilute solution of sodium chloride. What takes place? Place it aside where the light can shine upon it, and notice the change of color which gradually takes place. In the same way make the bromide by adding potassium bromide, and the iodide by adding potassium iodide to silver nitrate.

Photography.—The last experiments showed that the chloride, bromide, and iodide of silver are insoluble in water and are changed by light. The *art of photography* is based upon the changes which certain compounds, especially salts of silver, undergo when exposed to the light. A plate of glass, or celluloid film, is covered with a thin layer of an emulsion of the halogen salts of silver in gelatin, albumin, or collodion. The plate or the film is then exposed in the camera to the action of the light from the object to be photographed. Where the light acts upon the salt it is changed, while where the light does not act it is not changed. An image of the object towards which the plate was directed is thus left on the plate. The image must be *developed* by treating the plate with a solution of pyrogallic acid, ferrous oxalate, or some other reducing agent. After the image is developed, the plate is treated with something which dissolves the unchanged silver salt in order to "fix" it. The best substance for this purpose is a solution of sodium hyposulphite (called *hypo*).

CHAPTER XXII.

THE ALUMINIUM FAMILY—THE IRON FAMILY: IRON, COBALT, NICKEL.

Aluminium, Al (*At. Wt.* 27).—Aluminium is the only element of the family which it represents that need be taken up here. It is an extremely important element that occurs very widely distributed in nature. Among the many important and widely-distributed minerals that contain aluminium are feldspar, mica, and cryolite. The rock granite contains both feldspar and mica. Clay is essentially a silicate of aluminium.

Preparation of Aluminium.—Aluminium is prepared by passing an electric current through a bath of molten cryolite containing aluminium oxide in the form of corundum in solution. Iron pots are used. These form one electrode, while carbon rods are used for the other electrode.

Properties.—Aluminium has a strong lustre; its color is like that of tin. It is very strong and yet malleable. It is lighter than most metals in common use, its specific gravity being 2.5 to 2.7, while that of iron is 7.8, that of silver 10.57, and that of tin 7.3. Further, it does not change in dry or moist air. These properties give it great

value, and it is coming into more and more extensive use. It is used in the preparation of ornaments, and of useful articles in which lightness is of importance, as in telescopes and opera-glasses. An alloy with a small percentage of silver is used for the beams of chemical balances. Aluminium bronze, an alloy with copper, is also used quite extensively. High temperatures (about 3000° C.) are attained by burning cartridges containing aluminium and ferric oxide. Practical use is made of this process in welding.

Aluminium Oxide, Al_2O_3.—This compound occurs in nature in the form of ruby, sapphire, and corundum. It is very hard, and as *emery*, which is powdered corundum, is used for polishing. It is made artificially by heating the hydroxide, $Al(OH)_3$:

$$2Al(OH)_3 = Al_2O_3 + 3H_2O.$$

Alums.—Aluminium sulphate forms complex compounds with the sulphates of the alkali metals, all of which crystallize beautifully. Potassium alum is the best known of these. It may be regarded as derived from 2 molecules of sulphuric acid, $2H_2SO_4 = H_4S_2O_8$, by the substitution of 1 atom of aluminium for 3 atoms of hydrogen, and of 1 atom of potassium for the fourth atom of hydrogen; thus, $AlKS_2O_8$ or $AlK(SO_4)_2$. The crystals always contain 12 molecules of water, the complete formula being $AlK(SO_4)_2 + 12H_2O$. Similarly, sodium alum is $AlNa(SO_4)_2 + 12H_2O$, and ammonium alum, $AlNH_4(SO_4)_2 + 12H_2O$.

Uses of Alum.—Alum and other compounds are used in dyeing cotton cloth. Colors do not adhere to cotton fibre

as they do to wool and silk. On adding aluminium hydroxide or alum to the cotton the dye-stuffs unite with these and form insoluble compounds. Substances that have the power of combining with dye-stuffs in this way are called *mordants*. Alum is an acid salt and has the power of decomposing carbonates. It is therefore sometimes wrongly used as a constituent of "baking powders" in connection with sodium bicarbonate.

Aluminium Silicates.—The silicate of aluminium occurs in nature in enormous quantities, in combination with other silicates forming some of the most important minerals. The most abundant of these is ordinary *feldspar*, $AlKSi_3O_8$. When these silicates are subjected to the influence of the air, rain, frost, etc., they suffer decomposition. The silicate of the alkali metal dissolves and is washed away, while aluminium silicate is partly left behind and is also partly washed away. Pure aluminium silicate is known as *kaolin*, and has the composition $Al_4(SiO_4)_3 + 4H_2O$. The impure varieties are called clay.

Porcelain, etc.—Kaolin is used for making porcelain. For this purpose it is mixed with water and moulded into the proper shape and then heated to a high temperature in a furnace. The ordinary varieties of clay are used for making common earthenware vessels and bricks. Earthenware and porcelain are glazed in two ways: Porcelain, by coating it with an easily-fusible substance and heating to a high temperature; earthenware, by heating to a strong red heat in a furnace and throwing in a quantity of damp salt. The salt is decomposed and sodium silicate is formed. This fuses on the surface of the vessels and forms a layer which is not porous.

Ultramarine.—The substance known as ultramarine or *lapis lazuli* consists of a silicate of aluminium and sodium, together with a sulphide of sodium. The coloring-matter obtained by powdering it was formerly expensive, but it is now made artificially by the ton, and the color of the artificially-prepared substance is even more beautiful than that of the natural. It is made by heating a mixture of clay, dry sodium carbonate, sulphur, and wood-ashes without access of air.

Iron, Fe (*At. Wt.* 56).—At the present time it is undoubtedly true that iron is the most important metal for man. It occurs in the form of *magnetite*, Fe_3O_4, and *hematite*, Fe_2O_3; as the *carbonate*, or *siderite*, $FeCO_3$; in combination with sulphur as *iron pyrites*, FeS_2; and as *silicates* and *hydrated oxides*, or *hydroxides*. Iron in the metallic state is found in the form of meteors or masses which fall upon the earth from the outer space.

Extraction of Iron from its Ores.—The extraction of iron from its ores is theoretically simple, the essential steps being these:

(1) The conversion of the ore into the oxides, unless the oxides themselves are used.

This is accomplished by *roasting* them. If sulphides are roasted the sulphur passes off as sulphur dioxide, and the iron remains as the oxide. Further, water is driven off, and the carbonate is decomposed into the oxide and carbon dioxide.

(2) Reduction of the oxides by means of charcoal or coke.

This is accomplished by mixing the ore with the reducing agent and heating in a blast-furnace. The blast-

furnace is constructed of fire-brick and masonry. It is from 25 to 80 or 90 feet high, and from 15 to 18 feet wide in the widest part. An idea of the construction is given by Fig. 39. Alternate layers of ore and fuel are introduced into the top of the furnace. A *flux* is also added. This is usually limestone or quicklime. The object of the flux is to form a fusible substance with the earthy constituents of the ore. As the iron is reduced it melts, and the compound formed with the flux also melts. The molten iron being the heavier liquid sinks to the bottom followed by the other, which is called the *slag*. The iron collects in the bottom of the furnace, called

FIG. 39.

the crucible, and is drawn off in the liquid condition.
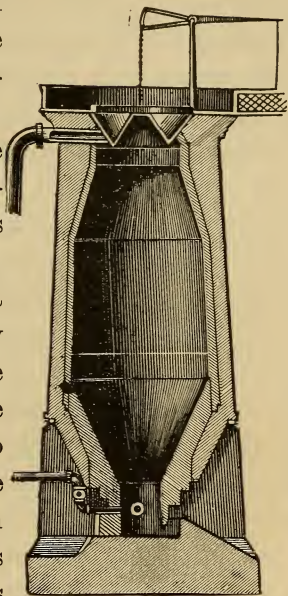
The reduction is largely accomplished by carbon monoxide. In the lower part of the furnace the fuel burns to carbon dioxide, but in its upward passage this comes in contact with hot carbon, and is then reduced to the monoxide. The hot monoxide in contact with the oxides of iron reduces these, and is itself converted into the dioxide.

Pig-iron.—The iron drawn off from the furnace is called *pig-iron.* It is always impure, containing phosphorus, sulphur, silicon, and as much as 2 to 6 per cent of carbon. It is brittle and easily fusible, and is used for casting, being known as *cast-iron.*

Wrought-iron.—When the carbon, silicon, and phosphorus are removed from *pig-iron* it becomes tough and malleable. It is now *wrought-iron*. Cast-iron is converted into wrought-iron in one of two ways:

(1) *Puddling.*—The puddling-furnace has a flat, oval hearth and a low, arched roof. The sides of the hearth are lined with iron ore (oxide). Coal is burned on a grate, and the flame passes into the furnace at one end and out at the other, thus coming in contact with the roof and being reflected downward upon the charge of iron. The *cast-iron* is melted, and the carbon and silicon are removed from it, partly by the oxygen of the air, but principally by that in the iron ore, which is itself thus reduced to wrought-iron.

(2) *Bessemer Process.*—Molten cast-iron is poured into a large vessel called a *converter*, Fig. 40. The carbon and silicon are oxidized, and removed by a blast of air forced through the metal from below. No fuel is used, as the heat generated by the oxidation of the carbon and silicon is sufficient to raise the temperature above 2100° C. By adding molten cast-iron to the product, *steel* containing any desired percentage of carbon is obtained.
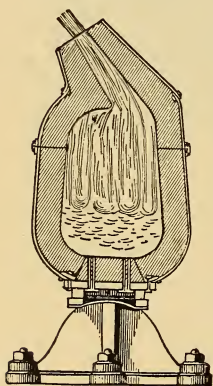
Fɪɢ. 40.

The Bessemer process is now employed on an enormous scale. The product is used in making cannon, rails, axles, etc.

Bessemer steel often contains less than 0.6 per cent of carbon.

Pure Iron.—Pure iron is almost unknown. It is a white metal with a strong lustre. In moist air it *rusts;* that is,

it becomes covered with a layer of oxide and hydroxide which is formed by the action of the air and water. The wire used for pianos is nearly pure; but if this is dissolved in hydrochloric or sulphuric acid, small black particles of carbon will remain undissolved. The odor noticed when ordinary iron is dissolved in acid is due to the presence of impurities.

Compounds of Iron.—Iron, like mercury and copper, forms two series of compounds which differ markedly from each other. These are the *ferrous* and *ferric* compounds. Thus with chlorine it forms two chlorides, one of which, *ferrous chloride*, has the composition expressed by the formula $FeCl_2$; the other, *ferric chloride*, by $FeCl_3$. It appears from a study of the relative weights of these chlorides in the state of vapor (see Chapter XIV., page 138) that the above formulas should be doubled, so that ferrous chloride is now commonly represented by Fe_2Cl_4, and ferric chloride by Fe_2Cl_6. For our purpose the simpler formulas will answer just as well. Similarly there are two oxides, FeO and Fe_2O_3; two sulphates, *ferrous sulphate*, $FeSO_4$, and *ferric sulphate*, $Fe_2(SO_4)_3$, etc.

Change of Ferrous to Ferric Compounds.—Ferrous compounds are slowly changed to ferric compounds by contact with the air, and readily by oxidizing agents, such as nitric acid, potassium chlorate, etc. When, for example, ferrous hydroxide, $Fe(OH)_2$, is exposed to the air suspended in water, it slowly changes to ferric hydroxide, $Fe(OH)_3$. The change is represented by the equation

$$2Fe(OH)_2 + H_2O + O = 2Fe(OH)_3.$$
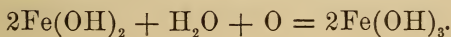
So, also, when ferrous chloride is left standing in solu-

tion in hydrochloric acid it changes to ferric chloride, and the change is rapidly effected by boiling with a little nitric acid which gives up oxygen:

$$2FeCl_2 + 2HCl + O = 2FeCl_3 + H_2O.$$
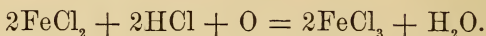
Ferrous Chloride, $FeCl_2$, is formed by dissolving iron in hydrochloric acid.

EXPERIMENT 119.—Dissolve a little iron wire in dilute hydrochloric acid. Hydrogen is evolved, accompanied by small quantities of other gases the formation of which is due to the presence of impurities in the iron, and carbon is left undissolved as a black residue. To a few drops of the solution in water in a test-tube add at once caustic soda. This precipitates ferrous hydroxide, $Fe(OH)_2$, which changes color rapidly, becoming finally reddish-brown. Pure ferrous hydroxide is white. As it passes to the ferric condition it becomes dirty green, and darker and darker until it is reddish-brown, which is the color of ferric hydroxide, $Fe(OH)_3$. Heat another small portion of the solution of ferrous chloride to boiling, add two or three drops of concentrated nitric acid and boil again. Repeat this operation two or three times. The ferrous chloride is thus oxidized to ferric chloride. It will be noticed that the color of the solution after the oxidation is reddish-yellow, whereas before the oxidation it was nearly colorless or slightly greenish. Add caustic soda to the solution of ferric chloride. A reddish-brown precipitate of ferric hydroxide will be formed. Just as in this case you have passed from ferrous chloride to ferric chloride by oxidation, so you can pass back again to the ferrous compound. Thus by adding a little zinc to a solution of ferric chloride in which hydrochloric acid is present, the hydrogen evolved extracts chlorine from the ferric chloride and converts it into ferrous chloride :

$$FeCl_3 + H = FeCl_2 + HCl.$$
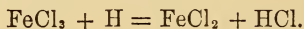
Ferrous Sulphate, $FeSO_4 + 7H_2O.$—This salt, which is commonly known as "green vitriol" or "copperas," is formed by the action of sulphuric acid on iron. [What is "white vitriol"? "blue vitriol"?] It is extensively used in the preparation of ink and in dyeing.

Inks.—Iron inks are made by treating solutions of tannic acid, which is obtained from nut-galls, with ferrous sulphate or copperas. There are many kinds of ink in use which are not made in this way. Printers' ink contains lamp-black. So also does India ink. Inferior inks are made of aniline dyes, which are made from substances obtained from coal-tar.

Iron Alum, $FeK(SO_4)_2 + 12H_2O$, is formed by bringing ferric sulphate and potassium sulphate together. It resembles ordinary alum, $AlK(SO_4)_2 + 12H_2O$, but differs from it in containing iron instead of aluminium.

Ferric Oxide, Fe_2O_3, occurs in nature in lustrous crystals, as *hematite*, and as a red mass. It is prepared on the large scale by heating copperas in the air, when the change represented in the following equation takes place:

$$2FeSO_4 = Fe_2O_3 + SO_3 + SO_2.$$
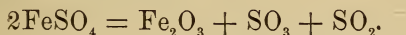
The oxide thus obtained is a dark-red powder called *rouge*. It is used for polishing glass and as a paint.

Ferroso-ferric Oxide, Fe_3O_4, or magnetic oxide of iron, is found in nature in the form of loadstone. It is formed when iron is burned in oxygen (see Experiment 26).

The *sulphides* of iron have been repeatedly mentioned.

Ferrous Sulphide, FeS, is made by heating sulphur and iron together in proper proportions. It is used in making hydrogen sulphide. [Explain how.]

Iron Pyrites, FeS_2, is a yellow crystallized substance very abundantly found in nature. When heated in a closed tube sulphur is given off. When heated in an open vessel as upon a shallow iron pan or spoon, the sulphur is oxidized to sulphur dioxide, and the iron is left in the

form of the oxide. [Verify these statements by experiment.]

Nickel, Ni (*At. Wt.* 58.3), is found in meteoric iron and in combination with arsenic. It forms two series of salts corresponding to the two hydroxides, nickelous hydroxide, $Ni(OH)_2$, and nickelic hydroxide, $Ni(OH)_3$. Nickel is used for making coins, and for plating other metals. It is not acted upon by the air.

Cobalt, Co (*At. Wt.* 58.6), is found in combination with arsenic and sulphur, and also in small quantities accompanying nickel in meteoric iron.

Cobalt compounds are used on account of their colors. Smalt is made by fusing glass with a cobalt compound, when a blue mass is obtained which is powdered and used as a paint. When cobaltic oxide and aluminium oxide are fused together a dark-blue substance is formed which is known as *cobalt ultramarine.*

CHAPTER XXIII.

MANGANESE—CHROMIUM—URANIUM—BISMUTH.

Manganese, Mn (*At. Wt.* 54.6).—Manganese is found in nature in the form of the oxides, of which manganese dioxide, or the black oxide of manganese, occurs most abundantly. With oxygen it forms the following compounds: *manganous oxide,* MnO; *manganic oxide,* Mn_2O_3; *manganoso-manganic oxide,* Mn_3O_4; *manganese dioxide,* MnO_2; and *permanganic anhydride,* Mn_2O_7.

Manganese resembles aluminium and iron in some respects. Like iron it forms two series of salts, the manganous and manganic series, which differ from each other very much as ferrous and ferric compounds do.

Chromium, Cr (*At. Wt.* 51.7).—This element is comparatively rare, and occurs almost entirely in combination with oxygen and iron as chromic iron, $FeCr_2O_4$ or $Fe(CrO_2)_2$.

Potassium Chromate, K_2CrO_4, is formed when finely-powdered chromic iron is heated with potassium carbonate and potassium nitrate.

Potassium Bichromate, $K_2Cr_2O_7$.—This is the form in which chromium is most frequently met with. It is formed from the chromate by adding acetic or nitric acid. The change is represented thus:

$$2K_2CrO_4 + 2HNO_3 = 2KNO_3 + K_2Cr_2O_7 + H_2O.$$

The relation between the chromate and the bichromate will be more readily understood by considering the acids from which they are derived. These are chromic acid, H_2CrO_4, and bichromic acid, $H_2Cr_2O_7$. The latter may be regarded as derived from the former by loss of water:

$$2H_2CrO_4 = H_2Cr_2O_7 + H_2O.$$

EXPERIMENT 120.—Potassium bichromate is converted into the chromate by adding a solution of potassium hydroxide until the color becomes pure yellow :

$$K_2Cr_2O_7 + 2KOH = 2K_2CrO_4 + H_2O.$$
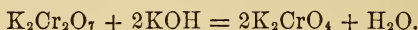
Convert 10 to 20 grams potassium bichromate into the chromate. Evaporate to crystallization. Compare the salt thus obtained with potassium bichromate.

EXPERIMENT 121.—Convert the potassium chromate just obtained into potassium bichromate by adding dilute nitric acid until the color is red. Evaporate to crystallization.

Both the chromate and bichromate are good oxidizing agents.

EXPERIMENT 122.—Treat a little of each salt in a test-tube with hydrochloric acid. [What evidence do you get that the salts are good oxidizing agents ?]

Chrome-yellow.—The chromates of lead and barium are insoluble in water. They are yellow. The lead salt is the well-known paint *chrome-yellow.*

EXPERIMENT 123.—Add a little of a solution of potassium chromate or bichromate to a solution of barium chloride, and of lead acetate or nitrate.

Chrome Alum is a salt related to ordinary alum, but containing chromium instead of aluminium. Its formula is $CrK(SO_4)_2 + 12H_2O$. The alums have analogous formulas:

Ordinary alum................$AlK(SO_4)_2 + 12H_2O$.
Iron alum....................$FeK(SO_4)_2 + 12H_2O$.
Chrome alum.................$CrK(SO_4)_2 + 12H_2O$.

Uranium, U (*At. Wt.* 237.7).—This element occurs mostly in the form of the oxide U_3O_4 known as *pitchblende*.

Bismuth, Bi (*At. Wt.* 206.9), occurs mostly native, and is obtained by heating the ores and allowing the molten bismuth to run out. In appearance it closely resembles antimony.

Bismuth forms alloys which melt at low temperatures. The best known of these is "fusible metal," which is composed of lead, tin, and bismuth. *Wood's metal* melts at 60°.5, while its lowest melting constituent, tin, melts at 233°. It consists of bismuth, lead, cadmium, and tin.

The chief compound of bismuth and oxygen is the yellow oxide Bi_2O_3, which is formed when bismuth is burned in the air.

The principal salt of bismuth is the nitrate $Bi(NO_3)_3 + 5H_2O$. Another nitrate of bismuth is used in medicine.

CHAPTER XXIV.

LEAD—TIN—PLATINUM—GOLD.

Lead, Pb (*At. Wt.* 205.35).—Lead occurs in combination in several forms in nature, as, for example, in the sulphate, carbonate, chromate, and sulphide. The sulphide, PbS, known as *galena*, or *galenite*, is the most important ore of lead.

Extraction of Lead from its Ore.—The extraction of lead from its ore is accomplished in one of two ways:

(1) By heating the sulphide with iron, when the latter combines with the sulphur, forming iron sulphide, while the lead is set free.

(2) By roasting the sulphide until it is partly converted into lead oxide and lead sulphate; then heating the mixture without access of air, when the two reactions take place which are represented in these equations:

$$PbS + 2PbO = 3Pb + SO_2;$$
$$PbS + PbSO_4 = 2Pb + 2SO_2.$$
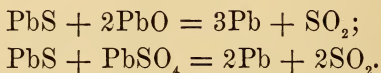
The lead is thus set free, and the sulphur driven off as sulphur dioxide.

Properties of Lead.—Lead is a bluish-gray metal with a high lustre which tarnishes rapidly when exposed to the air. It is soft and not very strong. It melts at about 325°. All lead salts are poisonous. Nitric acid

dissolves it, but hydrochloric and dilute sulphuric acids do not. It is precipitated in metallic form from a solution of one of its salts by metallic zinc. The formation is sometimes called the "lead-tree" or "Arbor Saturni."

EXPERIMENT 124.—Dissolve 6 or 8 grams lead acetate (sugar of lead) in a litre of water, add a few drops of acetic acid, and put the solution in a wide-mouthed bottle. Suspend a piece of sheet-zinc in the middle of the solution, and let it stand. The lead will be deposited slowly in crystallized form. At the same time the zinc will pass into solution. The zinc takes the place of the lead:

$$Zn + Pb(NO_3)_2 = Zn(NO_3)_2 + Pb.$$
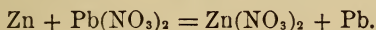
Lead Water-pipes.—Pipes for conveying water are frequently made of lead, and under most circumstances there is no danger in this; but some waters, particularly such as are rich in carbon dioxide, act upon lead and dissolve it in small quantity. Such waters are exceedingly dangerous. If air and water together act upon lead, it is much more readily acted upon than when air is excluded. In moist air lead tarnishes.

Oxides of Lead.—Lead forms three compounds with oxygen, viz.: *lead suboxide,* Pb_2O; *lead oxide,* PbO; and *lead peroxide,* PbO_2. *Red lead,* or *minium,* is a mixture or a compound of the oxide and peroxide, and has approximately the composition Pb_3O_4.

Lead Oxide, PbO, is commonly known by the name litharge. It is formed by the oxidation of molten lead in contact with the air.

Minium, Red Lead, $Pb_3O_4 (= 2PbO + PbO_2)$.—When litharge is heated in the air to 400° it takes up oxygen and is converted into *minium,* or *red lead.* When minium is heated to a high temperature it gives up oxygen and is again converted into yellow lead oxide. Treated with

nitric acid, a part is dissolved, forming lead nitrate, while lead peroxide, a brown powder, remains behind.

EXPERIMENT 125.—Treat a little minium with ordinary dilute nitric acid, and note the change in color. Does lead pass into solution ? How do you know ?

Lead Peroxide, PbO_2, conducts itself somewhat like manganese dioxide. When treated with hydrochloric acid chlorine is evolved:

$$PbO_2 + 4HCl = PbCl_2 + 2H_2O + 2Cl.$$

EXPERIMENT 126.—Treat a little lead peroxide with hydrochloric acid in a test-tube. In what form is the lead after the experiment ? Is the product soluble or insoluble in water ?

The *sulphate, chromate,* and *chloride* are formed by adding a soluble sulphate, chromate, and chloride to a solution of a lead salt. The chromate is the well-known *chrome-yellow.*

Lead Carbonate, $PbCO_3$, is the well-known and much-used pigment *white lead.* The objection to its use in a laboratory is that it turns black in the presence of even small quantities of hydrogen sulphide. Zinc-white does not act in this way, as zinc sulphide is a white substance.

Tin, Sn (*At. Wt.* 117.6).—Tin occurs in nature mostly as tin-stone, which is the oxide SnO_2. The metal is obtained from the ore by reducing with charcoal. It is a white metal that resembles silver in appearance. It is soft and malleable, and can be hammered out into very thin sheets, forming the well-known tin-foil. At 200° it is brittle; and at 233° it melts. It does not change in the air at ordinary temperatures. Ordinary concentrated nitric acid oxidizes it, the product being a compound of

tin, oxygen, and hydrogen, known as *metastannic acid*, which is a white powder insoluble in nitric acid and in water.

Extraction of Tin from its Ore.—The oxide or *tin-stone* is pulverized, mixed with charcoal, and heated in a furnace, when the tin appears in the molten condition.

Uses of Tin.—Owing to the fact that tin does not change in the air it is used as a covering for other metals. Ordinary *tin-ware* is made of sheets of iron covered with tin. An inferior variety of tin-ware is manufactured containing lead. If such ware is used for cooking-utensils or for making cans for preserving fruit and vegetables serious results may follow, as the acids of the food may dissolve enough lead to form poisonous liquids. Copper covered with tin is also used for various purposes, as for bath-tubs and pins.

Alloys of Tin.—Among the valuable alloys containing tin are *solder*, which consists of tin and lead; *britannia* which consists of 9 parts of tin and 1 part of antimony; bronze and bell-metal, which consist of tin and copper.

Soldering.—Soldering in general is any process by which metals are made to adhere by means of other metals added in the molten condition. Ordinary soldering consists in joining metals together by means of a solder consisting of about equal parts of lead and tin. In order that the solder may hold, it is necessary that the surfaces of the metal to which it is applied should be bright. This is brought about by the use of rosin or by washing with a little acid and then adding some borax, which in the molten condition dissolves any metallic oxides which may be present, leaving the surfaces bright. There is some danger in the

use of solder for tin cans, as it is possible for the contents to get in contact with the solder unless the work is done with unusual care.

Stannous and Stannic Compounds. — Tin forms two classes of compounds, the stannous and stannic compounds. These do not bear to each other the same relation as that which exists between cuprous and cupric compounds, or that between ferrous and ferric compounds. In stannous compounds the tin appears to be bivalent, as indicated by the formulas $SnCl_2$, SnO, SnS, which respectively represent stannous chloride, oxide, and sulphide. In stannic compounds, on the other hand, the tin appears to be quadrivalent, as indicated by the formulas $SnCl_4$, SnO_2, SnS_2, which respectively represent stannic chloride, oxide, and sulphide.

Stannous Chloride, $SnCl_2$, and **Stannic Chloride**, $SnCl_4$, are the most used compounds of tin. They find application in dyeing. The former is known as *tin-salt*. It is made by dissolving tin in hydrochloric acid.

Stannic Sulphide, SnS_2, is a yellow substance used under the name *mosaic gold* as a pigment in decorating.

Platinum, Pt (*At. Wt.* 193.3), occurs almost always accompanied by the rare metals iridium, palladium, and osmium, in the form of alloys. The ore is found in the Ural Mountains, in California, Australia, and a few other places. It is prepared by treating the ore with strong *aqua regia*, which dissolves the platinum, together with some iridium. The chlorplatinic acid thus formed is precipitated by means of ammonium chloride, with which, as with potassium chloride, it forms a difficultly soluble compound, $(NH_4)_2PtCl_6$. When this is heated to a suffi-

ciently high temperature it is decomposed, leaving metallic platinum behind.

Properties of Platinum.—Platinum is a grayish-white metal with a high lustre. Its specific gravity is 21.15, it being one of the heaviest substances known. The specific gravity of iron is 7.8, that of lead 11.4. In other words, a piece of platinum weighs nearly three times as much as a piece of iron of the same dimensions, and nearly twice as much as a piece of lead of the same bulk. Platinum is not dissolved by hydrochloric, nitric, or sulphuric acid; but *aqua regia* dissolves it, forming chlorplatinic acid, H_2PtCl_6. Fusing caustic alkalies attack it; sodium carbonate does not. It does not change in the air, and does not melt except in the flame of the oxyhydrogen blow-pipe or in the electric furnace. It resists the action of most substances.

Uses of Platinum.—The properties of platinum make it extremely valuable to the chemist. Platinum crucibles and evaporating-dishes, foil, and wire are in constant use in every chemical laboratory, and it is difficult to see how we could get along without them. Large retorts of platinum are used for the purpose of concentrating sulphuric acid and distilling it.

Gold, Au (*At. Wt.* 195.7).—Gold usually occurs native. It is found enclosed in quartz, or more frequently in quartz sand. It is separated mechanically by washing, and then extracted with mercury, which forms an amalgam with it. The amalgam is afterwards heated, when the mercury passes over and the gold remains behind. Gold is also extracted from its ores by means of chlorine or potassium cyanide.

Properties of Gold.—Gold is a yellow metal with a high lustre. It is quite soft and extremely malleable. It can be beaten into leaves not more than $\frac{1}{10000}$ of a millimetre thick. Its specific gravity is 19.3. It combines directly with chlorine, but not with oxygen. Hydrochloric, nitric, and sulphuric acids do not act upon it; but *aqua regia* dissolves it, forming chlorauric acid, $HAuCl_4$. On account of the fact that gold resists the action of other substances it was formerly spoken of as the *king of metals*, and therefore the mixture of hydrochloric and nitric acids which dissolves it was called *aqua regia*, or royal water.

Uses of Gold.—Gold ware and coin are made of an alloy of gold and copper. The standard gold coin of the United States contains nine parts of gold to one of copper. The composition of gold for jewelry is usually stated in *carats*. Pure gold is 24-carat gold; 20-carat gold contains 20 parts gold and 4 parts copper; 18-carat gold contains 18 parts gold and 6 parts copper, etc.

CHAPTER XXV.

SOME FAMILIAR COMPOUNDS OF CARBON.

Organic Chemistry.—When the compounds that are obtained from plants and animals were first studied it was supposed that they are entirely different in every way from the compounds obtained from earthy or mineral substances. The former were called *organic substances*, for the reason that they were obtained from organized beings; while the latter were called *inorganic substances*. Organic substances were the subject of *Organic Chemistry*, and inorganic substances formed the subject of *Inorganic Chemistry*. These names are still in use, though they have lost their original meaning. Organic Chemistry means now only the *Chemistry of the Compounds of Carbon.*

Occurrence of the Compounds of Carbon.—The most widely distributed compound of carbon is carbon dioxide, which, as you have learned, is the starting-point of all life on the globe. All living things are formed from it either directly or indirectly. The substances that occur in largest quantity in plants are cellulose and starch; but besides these a large number of other substances are found, as the sugars, the alkaloids,—of which, morphine, quinine, and nicotine, are examples,—oxalic acid, malic acid, tartaric acid, citric acid. In animals, too, occur many substances, as the fats, albumin, fibrin, etc.

Certain natural processes that are not thoroughly understood have given rise to the formation of a complex mixture of organic compounds, principally hydrocarbons, in *petroleum* (page 116).

Distillation of Coal.—The destructive distillation of coal for the purpose of making illuminating-gas, and the formation of *coal-tar*, have already been referred to. Coal-tar is one of the most important sources of compounds of carbon. The hydrocarbons benzene, C_6H_6, toluene, C_7H_8, xylene, C_8H_{10}, naphthalene, $C_{10}H_8$, anthracene, $C_{14}H_{10}$, etc., are obtained from this source.

Distillation of Wood.—Wood is heated in closed vessels mostly for the purpose of making charcoal, as already explained. Among the products obtained from this source are *wood-alcohol*, or *methyl alcohol*, and *pyroligneous acid*, or *acetic acid*. Large quantities of acetic acid are prepared in this way.

Distillation of Bones.—In order to make bone-black, bones are subjected to destructive distillation. The oil that passes over, called *bone-oil*, is collected.

Fermentation.—A number of the most important compounds of carbon are formed by a process known as *fermentation*. This is a general term meaning any process in which a chemical change is effected by means of minute animal or vegetable organisms. The best known example of fermentation is that of sugar, which gives rise to the formation of ordinary *alcohol*. The organism that causes the change is called a *ferment*.

Classes of Compounds of Carbon.—The chief classes of these compounds are the *hydrocarbons*, some of which have already been treated of (see page 116); the *alcohols;* the

acids; the *ethers;* and the *ethereal salts.* First a few of the best known examples of each of these classes will be taken up, and afterwards some other familiar compounds which do not belong to any one of these classes.

ALCOHOLS.

Methyl Alcohol, Wood-spirit, Wood Alcohol, CH_4O.— This is formed by the distillation of wood, and is separated from the other products that are formed at the same time. It has, when pure, a pleasant odor and taste and acts upon the animal system much as ordinary alcohol does. It burns without giving light or smoke, and may therefore be used in lamps for heating purposes as ordinary alcohol is. It is used in the manufacture of varnishes.

Ethyl Alcohol, Spirits of Wine, C_2H_6O.—This well-known substance is formed by the fermentation of grape-sugar or glucose.

EXPERIMENT 127. — Dissolve 150 grams commercial grape-sugar, or 150 c.c. table syrup, in 1 to 2 litres of water in a flask,
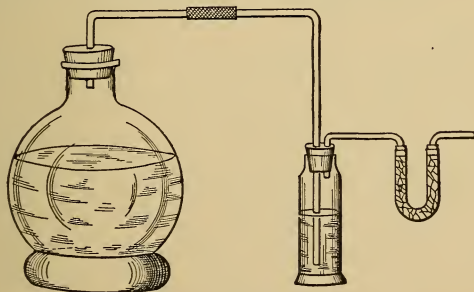
FIG. 41.

Connect the flask by means of a bent glass tube with a cylinder or bottle containing clear lime-water. The vessel containing the lime-water must be provided with a cork with two holes. Through

one of these passes the tube from the fermentation-flask; through the other a tube connecting with a vessel containing solid caustic potash, the object of which is to prevent the carbon dioxide in the air from acting upon the lime-water. The arrangement of the apparatus is shown in Fig. 41. Now add to the solution of grape-sugar or syrup a little fresh brewer's yeast ; close the connections and allow to stand. Soon an evolution of gas will begin, and, as this passes through the lime-water, a precipitate will be formed which can be shown to be calcium carbonate.

What Change takes place in the Sugar?—If the solution in the flask is examined carefully it will be found to contain alcohol and no sugar. Grape-sugar has the composition expressed by the formula $C_6H_{12}O_6$. By fermentation it is decomposed, forming alcohol, C_2H_6O, and carbon dioxide, CO_2. The decomposition is expressed by the equation

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2.$$
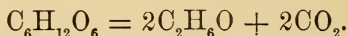
What Causes the Change?—It has been found that the change of grape-sugar is caused by small organized bodies that grow in the solution. These bodies are contained in ordinary yeast.

Germs in the Air.—When fruit-juices that contain sugar are exposed to the air they undergo fermentation without the addition of yeast. This is due to the fact that the germs or seeds of the bodies that cause fermentation are everywhere floating in the air. Hence, when a liquid in which these seeds can grow is exposed to the air, the bodies are formed, and fermentation takes place.

Different Kinds of Fermentation.—The fermentation that yields alcohol is only one of many kinds. Among the others are: (1) *lactic-acid fermentation,* which takes place

in the souring of milk; and (2) *acetic-acid fermentation,* which causes the transformation of alcohol into acetic acid. The latter ferment is contained in " mother of vinegar."

Distillation of Fermented Liquids.—In order to get the alcohol from liquids that have undergone fermentation they must be distilled. For this purpose very efficient forms of stills have been devised, so that the alcohol passes over nearly free from other substances. Usually it contains impurities known as *fusel oil.*

Properties of Alcohol.—Pure ethyl alcohol has a peculiar, pleasant odor. It remains liquid at very low temperatures, but has recently been converted into a solid at a temperature of $- 130°.5$. It burns with a flame that does not deposit soot, and was hence formerly much used in laboratories for heating purposes, and is still used where gas cannot be obtained. Its effects upon the human system are well known. It intoxicates when taken in dilute form, while in large doses it is poisonous. It lowers the temperature of the body when taken internally, although it causes a sensation of warmth.

Uses of Alcohol.—Alcohol is the principal solvent for organic substances. It is hence extensively used in the arts, as in the manufacture of varnishes, perfumes, and tinctures of drugs. The many beverages in use owe their intoxicating power to the presence of alcohol. The milder forms of beer contain from 2 to 3 per cent; light wines about 8 per cent; while whiskey, brandy, etc., sometimes contain as much as 60 to 75 per cent.

Glycerin, $C_3H_8O_3$.—Glycerin is an alcohol that occurs very widely distributed as a constituent of fats. The relation it bears to the fats will be explained when the acids

that enter into the fats are taken up. It is obtained from the fats by boiling them with an alkali like caustic soda or caustic potash, or by heating them with steam.

Properties.—Glycerin is a thick, colorless liquid with a sweetish taste. It attracts moisture from the air, and is hence used to keep surfaces moist.

Acids.

Formic Acid, CH_2O_2.—This acid occurs in nature in red ants, in stinging-nettles, in the shoots of some of the varieties of pine, and elsewhere. It is a colorless liquid. Dropped on the skin, it causes extreme pain and produces blisters.

Acetic Acid, $C_2H_4O_2$.—This is the acid contained in vinegar which gives to it its value. It is formed from alcoholic liquids by exposing them to the air, in consequence of the presence of a microscopic organism which is contained in what is commonly known as "mother of vinegar." The formation of acetic acid from alcohol is due to the action of oxygen as represented in the equation

$$\underset{\text{Alcohol.}}{C_2H_6O} + O_2 = \underset{\text{Acetic acid.}}{C_2H_4O_2} + H_2O.$$
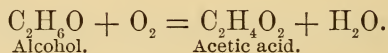
But oxygen alone does not effect the change. When the ferment is present the oxidation takes place. Acetic acid is also obtained by distilling wood. Hence the names *pyroligneous acid* and *wood-vinegar*.

Properties.—Acetic acid is a clear, colorless liquid. It has a very penetrating, pleasant, acid odor, and a sharp taste. The pure substance acts upon the skin like formic acid, causing pain and raising blisters.

Uses.—Acetic acid is extensively used, chiefly in the dilute form known as vinegar. It is used in calico-printing in the form of iron and aluminium salts. With iron it gives hydrogen, which is needed in the manufacture of certain compounds used in making dyes.

Salts of Acetic Acid.—The best-known salts of acetic acid are *lead acetate*, $Pb(C_2H_3O_2)_2$, commonly called *sugar of lead;* and *copper acetate*, $Cu(C_2H_3O_2)_2$, a variety of which is known as *verdigris*.

Fatty Acids.—Formic and acetic acids are the first members of an *homologous series* (see page 118). Some of the more important members are named in the following table:

Formic	acid	CH_2O_2.
Acetic	"	$C_2H_4O_2$.
Propionic	"	$C_3H_6O_2$.
Butyric	"	$C_4H_8O_2$.
Valeric	"	$C_5H_{10}O_2$.
Palmitic	"	$C_{16}H_{32}O_2$.
Stearic	"	$C_{18}H_{36}O_2$.

They are called *fatty acids* for the reason that many of them are obtained from fats.

Butyric Acid, $C_4H_8O_2$, is of special interest because it is obtained from butter by boiling with caustic potash. It occurs also in many other fats. There is a *butyric-acid ferment* contained in putrid cheese which has the power of converting sugar into butyric acid.

Palmitic Acid, $C_{16}H_{32}O_2$, is obtained from many fats, but palm-oil is especially rich in it.

Stearic Acid, $C_{18}H_{36}O_2$, is the acid contained in the fat known as *stearin*. The so-called "*stearin* candles" are made of a mixture of palmitic and stearic acids.

Soaps.—Soaps are the alkali salts of the acids contained in fats, especially of palmitic and stearic acids. Fats are

compounds of these acids with glycerin. When the fats are boiled with an alkali, as caustic soda, the corresponding salts of the acids are formed, while the glycerin is set free. The palmitate and stearate of potassium and sodium are the soaps.

EXPERIMENT 128.—In an iron pot boil a quarter of a pound of lard with a solution of 40 grams caustic soda in 250 c.c. of water for an hour or two. After cooling add a strong solution of sodium chloride. The soap formed will separate and rise to the top of the solution, where it will finally solidify. Dissolve some of the soap thus obtained in water.

Use of Soap.—The cleansing power of soap depends upon the fact that it dissolves the oily film on the surface of the skin and thus facilitates the removal of the foreign substances commonly known as dirt.

Action of Soap on Hard Waters.—As has been explained, a hard water is one that contains salts in solution. *Temporary hardness* is that which is caused by calcium carbonate held in solution in the water by carbon dioxide. *Permanent hardness* is caused by calcium sulphate or magnesium salts. The calcium and magnesium salts of palmitic and stearic acids are difficultly soluble in water. Therefore, when soap is added to a hard water these salts are precipitated, and give the water a hard feeling. In attempting to wash the hands with soap in a hard water they become covered with a thin layer of the insoluble salts which prevents them from rubbing freely over each other, and makes them feel sticky. Before the soap can do any good all the calcium must be precipitated. The action in the case of temporary hardness is represented by the equation

$$2NaC_{16}H_{31}O_2 + CaCO_3 = Ca(C_{16}H_{31}O_2)_2 + Na_2CO_3.$$

Soap.   Calcium palmitate.
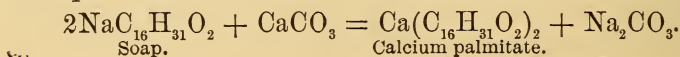
In the case of permanent hardness it is represented by the equation

$$2NaC_{16}H_{31}O_2 + CaSO_4 = Ca(C_{16}H_{31}O_2)_2 + Na_2SO_4.$$
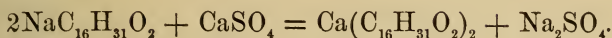
EXPERIMENT 129.—Make some hard water by passing carbon dioxide through dilute lime-water until the precipitate first formed is dissolved again. Filter. Make a solution of soap by shaking up a few shavings of soap with water. Filter. Add the solution of soap to the hard water. Is a precipitate formed? Rub a piece of soap between the hands wet with the hard water.

EXPERIMENT 130.—Make some hard water by shaking 1 or 2 litres of water with a little powdered gypsum. Perform with it the same experiments as those first performed with the water containing calcium carbonate.

Soap and Civilization.—A great chemist and philosopher has said that the quantity of soap used in a country is a measure of the civilization of the country. Certain it is that soap is only used by civilized people, and that by them it is used in enormous quantities. In some farm-houses a primitive method for the manufacture of soap is practised, consisting in treating refuse fats with the lye extracted from wood-ashes. A soft soapy mass is thus obtained known as "soft-soap." Fats form the starting-point in the manufacture of all soap. These are generally treated with caustic soda. Caustic soda is now largely made from sodium chloride by the action of an electric current (see page 182).

Oxalic Acid, $C_2H_2O_4$.—This acid occurs very widely distributed in nature, as in the *sorrels*, which owe their acid taste to the presence of acid potassium oxalate, KC_2HO_4; and as the ammonium salt in guano. It is probably one of the first substances formed from carbon dioxide in the plant. It can be manufactured by heating wood shavings

or sawdust with caustic soda and caustic potash. Oxalic acid is an active poison. It is used in calico-printing, and in cleaning brass and copper surfaces.

Lactic Acid, $C_3H_6O_3$.—Lactic acid is made by the fermentation of sugar by means of the *lactic-acid ferment*. The reaction effected by the ferment is represented by the equation

$$C_6H_{12}O_6 = 2C_3H_6O_3.$$
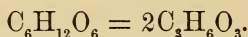
Malic Acid, $C_4H_6O_5$.—This acid is very widely distributed in the vegetable kingdom, as in apples, cherries, etc.

Tartaric Acid, $C_4H_6O_6$.—Tartaric acid occurs very widely distributed in fruits, sometimes uncombined, sometimes in the form of the potassium or calcium salt; as, for example, in grapes, berries of the mountain-ash, potatoes, cucumbers, etc., etc. It is prepared from "cream of tartar." This is acid potassium tartrate, which is formed when grape-juice ferments.

Citric Acid, $C_6H_8O_7$.—Citric acid, like malic and tartaric acids, is very widely distributed in nature in many varieties of fruit, especially in lemons. It is also found in currants, whortleberries, raspberries, gooseberries, etc., etc. It is prepared from lemon-juice: 100 parts of lemons yield $5\frac{1}{2}$ parts of the acid. It is a solid, crystallized substance, soluble in water. It is sometimes used for the purpose of making lemonade without lemons, and there is no objection to its use for this purpose.

ETHERS.

Ether, $C_4H_{10}O$.—Ordinary ether is the best-known representative of the class of compounds called *ethers*. It is

formed from ordinary alcohol by treating it with sulphuric acid and distilling. The action is represented by the equation

$$2C_2H_6O = C_4H_{10}O + H_2O.$$
$$\underset{\text{Alcohol.}}{} \quad \underset{\text{Ether.}}{}$$

Ether is a liquid which boils at a low temperature and takes fire and burns readily. Inhaled it produces insensibility to pain. It is therefore called an *anæsthetic*.

ETHEREAL SALTS.

Action of Acids upon Alcohols.—When an acid acts upon an alcohol it is neutralized, though not as readily as when it acts upon a base. The product is a substance that resembles a salt and is called an ethereal salt. Thus when nitric acid acts upon alcohol this reaction takes place:

$$C_2H_6O + HNO_3 = C_2H_5NO_3 + H_2O.$$
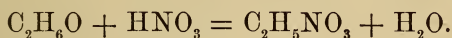
The product $C_2H_5NO_3$, called ethyl nitrate, is an ethereal salt. The alcohol acts as if it were a substance like caustic potash and made up thus, $C_2H_5 \cdot OH$. The resemblance between its action and that of caustic potash is shown by the equations

$$KOH \quad + HNO_3 = KNO_3 \quad + H_2O, \text{ and}$$
$$C_2H_5OH + HNO_3 = C_2H_5NO_3 + H_2O.$$
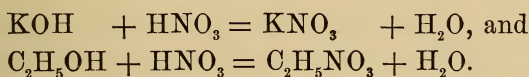
Saponification.—When an ethereal salt is boiled with a caustic alkali it is decomposed, the products being an alcohol and an alkali salt. Thus when ethyl nitrate is boiled with caustic potash, potassium nitrate and alcohol are formed:

$$C_2H_5NO_3 + KOH = C_2H_5OH + KNO_3.$$

This process is called *saponification*, because the most important example is furnished by soap-making.

Fats.—The fats are ethereal salts in the formation of which glycerin, as the alcohol, and three acids take part. The three acids are palmitic and stearic acids, already mentioned, and *oleic acid*, $C_{18}H_{34}O_2$. Although the composition of these substances is comparatively complex, the way they act upon one another is simple, and is the same as the action of nitric acid upon alcohol in forming ethyl nitrate. The fats, then, are the palmitate, stearate, and oleate of *glyceryl*, C_3H_5, which bears to glycerin very much the same relation that *ethyl*, C_2H_5, bears to alcohol. When a fat is boiled with caustic soda, the sodium salts of the acids, contained in the fat, and glycerin are formed.

Butter consists of ethereal salts of glycerin and several fatty acids, among which are palmitic, stearic, and butyric acids. *Oleo-margarin* is an artificial butter made from other fats than that from milk.

Ethereal Salts as Essences.—The ethereal salts generally have pleasant odors, and it is to their presence that many fruits owe their flavors. Some of the compounds are now made artificially and used instead of the natural extract of the fruit. Thus the *ethyl salt of butyric acid* is used under the name of *essence of pineapples*, and the *amyl salt of valeric acid* under the name *essence of apples*.

Nitroglycerin.—Among the more important ethereal salts of glycerin are the *nitrates*. Two of these are known, viz., the mono-nitrate, $C_3H_5 \begin{cases} NO_3 \\ OH \\ OH \end{cases}$, and the *tri-nitrate*, $C_3H_5(NO_3)_3$, the latter being the chief constituent of *nitroglycerin*. Nitroglycerin is prepared by treating

glycerin with a mixture of concentrated sulphuric and nitric acids. It is a pale yellow oil which is insoluble in water. At − 20° it crystallizes in needles. It explodes very violently by concussion. It may be burned in an open vessel, but if heated above 250° it explodes. *Dynamite* is infusorial earth * impregnated with nitroglycerin. Nitroglycerin is the active constituent of a number of explosives.

Relations between the Compounds Considered.

Comparison of the Formulas.—On comparing the formulas of the hydrocarbons of the marsh-gas series (see page 117) with those of the simplest alcohols and the fatty acids, it will be seen that these compounds are all related in a simple way. Below are lists of a few of the hydrocarbons, alcohols, and acids:

Hydrocarbons.	Alcohols.	Acids.
CH_4	CH_4O	CH_2O_2
C_2H_6	C_2H_6O	$C_2H_4O_2$
C_3H_8	C_3H_8O	$C_3H_6O_2$
C_4H_{10}, etc.	$C_4H_{10}O$, etc.	$C_4H_8O_2$, etc.

Each of these series is an homologous series.

Alcohols.—Alcohols have been shown to be derived from the hydrocarbons by the substitution of hydroxyl, OH, for one or more hydrogen atoms, or from water by substituting a group of atoms consisting of carbon and hydrogen for one of the hydrogen atoms of the water. An alcohol,

---

* That is to say, earth made up of the microscopic flinty shells which constitute the fossil remains of certain minute and simple plants.

then, is a hydroxide, just as a metallic base is; only, instead of consisting of a metal in combination with hydroxyl, it consists of a group of atoms of carbon and hydrogen in combination with hydroxyl.   Thus:

Metallic Bases.	Alcohols.
$K(OH)$	$CH_3(OH)$
$Na(OH)$	$C_2H_5(OH)$
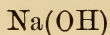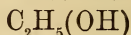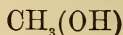
More Complex Alcohols.—Just as lime is a more complex base than caustic potash, as shown by the formulas KOH and $Ca(OH)_2$, so there are more complex alcohols than ordinary alcohol.   A good example is furnished by glycerin, $C_3H_8O_3$, which has been shown to be a hydroxide corresponding to aluminium hydroxide, $Al(OH)_3$, a fact which is represented by the formula $C_3H_5(OH)_3$.   It may be called glyceryl hydroxide, the complex, C_3H_5, being known as glyceryl.

Radicals or Residues.—The groups of atoms of hydrogen and carbon contained in the alcohols are called *radicals* or *residues*. So we may say that an alcohol is water in which a radical has been substituted for half of the hydrogen.

$$HOH \qquad\qquad C_2H_5OH$$
Water.   Ordinary alcohol.
$$HOH$$
$$HOH \qquad\qquad C_3H_5 \begin{cases} OH \\ OH \\ OH \end{cases} = C_3H_8O_3.$$
$$HOH$$
Water.   Glycerin.
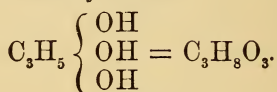
Acids.—Just as the alcohols have been shown to be derived from water, so the organic acids have been shown to be derived from carbonic acid.   Carbonic acid itself is not known.   But the carbonates are derived from an acid

of the formula H_2CO_3, or $CO \begin{cases} OH \\ OH \end{cases}$. If, in this acid, a radical, as, for example, ethyl, C_2H_5, is substituted for a hydroxyl, a substance of the formula $CO \begin{cases} C_2H_5 \\ OH \end{cases}$ or $C_3H_6O_2$ is the result. If methyl, CH_3, instead of ethyl is substituted for the hydroxyl, the product is $CO \begin{cases} CH_3 \\ OH \end{cases}$ or $C_2H_4O_2$, which is acetic acid. In a similar way all the organic acids are believed to be derived from carbonic acid.

CHAPTER XXVI.

OTHER COMPOUNDS OF CARBON.

The Carbohydrates.—The carbohydrates form an important group of carbon compounds which includes the most abundant substances found in the vegetable kingdom. Besides carbon they contain hydrogen and oxygen generally in the proportion to form water. Hence they are called carbohydrates. The chief compounds included under this head are *grape-sugar* or *glucose, fructose* (or *levulose*), *maltose, cane-sugar, starch, cellulose, gum,* and *dextrin.*

Grape-sugar, Glucose, Dextrose, $C_6H_{12}O_6$. — Dextrose occurs very widely distributed in the vegetable kingdom, particularly in sweet fruits. It is found also in honey and, further, in the liver and the blood.

Formation of Dextrose.—Dextrose or glucose is formed from several of the carbohydrates by boiling with dilute mineral acids, or by the action of ferments. Its formation from cane-sugar takes place according to this equation, equal quantities of dextrose and fructose being formed:

$$\underset{\text{Cane-sugar.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose.}}{C_6H_{12}O_6} + \underset{\text{Fructose.}}{C_6H_{12}O_6.}$$
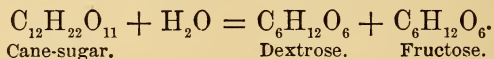
Its formation from starch is represented by this equation:

$$\underset{\text{Starch.}}{C_6H_{10}O_5} + H_2O = \underset{\text{Dextrose.}}{C_6H_{12}O_6.}$$
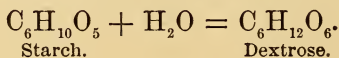
Manufacture of Dextrose or Glucose.—Dextrose is prepared on the large scale from corn-starch in the United States, and from potato-starch in Germany. The change is usually effected by boiling with dilute sulphuric acid. The acid is afterwards removed by treating with chalk, and filtering. [Explain how this removes the acid.] The filtered solutions are evaporated either to a syrupy consistency, and sent into the market under the names " glucose," " mixing-syrup," etc., or to dryness, the solid product being known as " grape-sugar."

Properties.—Dextrose crystallizes from concentrated solutions, and as seen in commercial " granulated grape-sugar " looks very much like granulated cane-sugar. It is sweet, but not as sweet as cane-sugar. It is estimated that the sweetness of dextrose is to that of cane-sugar as 3 : 5. Under the influence of yeast it ferments, yielding mainly alcohol and carbon dioxide. Putrid cheese transforms it into lactic acid, and then into butyric acid.

Levulose (*Fruit-sugar*), $C_6H_{12}O_6$.—This form of sugar occurs with dextrose in fruits; and is formed by the action of dilute acids or ferments on cane-sugar, which breaks down according to the equation

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6.$$
$$\text{Cane-sugar.} \qquad\qquad \text{Dextrose.} \quad \text{Levulose.}$$
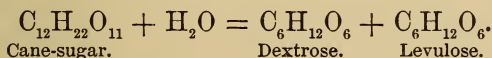
As cane-sugar is found in unripe fruits, it is probable that the change represented in the equation takes place during the process of ripening.

Cane-sugar, $C_{12}H_{22}O_{11}$. — This well-known variety of sugar occurs widely distributed in nature—in sugar-cane, sorghum, the Java palm, the sugar-maple, beets, madder-

root, coffee, walnuts, hazel-nuts, sweet and bitter almonds; in the blossoms of many plants, etc., etc.

Sugar-refining.—Sugar is obtained mainly from the sugar-cane and beets. In either case the processes of extraction and refining are largely mechanical. When sugar-cane is used, this is macerated with water to dissolve the sugar. Thus a dark-colored solution is obtained. This is evaporated, and then passed through filters of bone-black by which the color is removed. The clear solution is then evaporated in open vessels to some extent; and, finally, in large closed vessels called "vacuum-pans," from which the air is partly exhausted, so that the boiling takes place at a lower temperature than would be required under the ordinary pressure of the atmosphere. The mixture of crystals and mother-liquors obtained from the "vacuum-pans" is freed from the liquid by being brought into the "centrifugals." These are funnel-shaped sieves which are revolved rapidly, the liquid being thus thrown by centrifugal force through the openings of the sieve, while the crystals remain behind and are thus nearly dried. The final drying is effected by placing the crystals in a warm room.

Molasses.—The mother-liquors obtained from the "centrifugals" are further evaporated, and yield lower grades of sugar; and, finally, a syrup is obtained which does not crystallize. This is *molasses*.

Properties of Sugar.—Sugar crystallizes from water in large well-formed prisms. When heated to 210° to 220°, it loses water, and is converted into a substance called *caramel*, which is more or less brown in color. When boiled with dilute acids, cane-sugar is split into equal

parts of dextrose and levulose. The mixture of the two is called *invert-sugar*. Yeast gradually transforms cane-sugar into dextrose and levulose, and these then undergo fermentation. Cane-sugar does not ferment.

Sugar of Milk, Lactose, $C_{12}H_{22}O_{11} + H_2O$.—This sugar occurs in the milk of all mammals. It is obtained in the manufacture of cheese. Cows' milk consists of water, casein, butter, sugar of milk, and a little inorganic material, in about the following proportions:

Water	87	per cent.
Casein	4	"
Butter	$3\frac{1}{2}$	"
Sugar of milk	$4\frac{3}{4}$	"
Mineral matter	$\frac{3}{4}$	"
	100	

Cheese is made by adding rennet to the milk, which causes the separation of the casein. The sugar of milk remains in solution, is separated by evaporation, and purified by recrystallization. It has a slightly sweet taste, and is much less soluble in water than cane-sugar.

Souring of Milk.—Sugar of milk ferments under certain circumstances, and is transformed mostly into lactic acid. The souring of milk is a result of this fermentation. The lactic acid formed coagulates the casein, that is to say, causes it to appear in insoluble semi-solid form.

Cellulose, $C_6H_{10}O_5$.—Cellulose forms, as it were, the groundwork of all vegetable tissues. It presents different appearances and different properties, according to the source from which it is obtained; but these differences are due to substances with which the cellulose is mixed; and when they are removed, the cellulose left behind appears to be the same thing, no matter what its source may have

been. The coarse wood of trees and the tender shoots of the most delicate plants consist essentially of cellulose. Cotton-wool, hemp, and flax consist almost wholly of cellulose.

Properties.—Cellulose does not easily crystallize, and is insoluble in all ordinary solvents. It dissolves in concentrated sulphuric acid. If the solution is diluted and boiled, the cellulose is converted into dextrin and dextrose. It will thus be seen that rags, paper, and wood, all of which consist largely of cellulose, might be used for the preparation of dextrose or glucose, and consequently of alcohol.

Gun-cotton, Pyroxylin, Nitro-cellulose.—Cellulose has some of the properties of alcohols; among them the power to form ethereal salts with acids. Thus, when treated with nitric acid it forms several nitrates, just as glycerin forms the nitrates known as nitro-glycerin (which see). The nitrates are explosive, and are used for blasting under the name *gun-cotton*.

Collodion.—A solution of gun-cotton in a mixture of ether and alcohol is known as *collodion solution*, which is much used in photography. When poured upon any surface, such as glass, the ether and alcohol rapidly evaporate, leaving a thin coating of the nitrates.

Celluloid.—Celluloid is an intimate mixture of gun-cotton and camphor. As it is plastic at a slightly elevated temperature, it can easily be moulded into any desired shape. When cooled it hardens.

Paper.—Paper in its many forms consists mainly of cellulose. The essential features in the manufacture of paper are, first, the disintegration of the substances used. This is effected partly mechanically and partly by boiling

with caustic soda or with acid sodium sulphite. Then the resulting mass is converted into *pulp* by means of knives placed on rollers. The pulp, with the necessary quantity of water, is then passed between rollers. Chiefly rags of cotton or linen are used in the manufacture of paper; wood and straw are also used.

Starch, $C_6H_{10}O_5$.—Starch is found everywhere in the vegetable kingdom in large quantity, particularly in all kinds of grain, as maize, wheat, etc.; in tubers, as the potato, arrowroot, etc.; in fruits, as chestnuts, acorns, etc.

Manufacture of Starch.—In the United States starch is manufactured mainly from maize; in Europe, from potatoes. The processes made use of are mostly mechanical. The maize is first treated with warm water; the softened grain is then ground between stones, a stream of water running constantly into the mill. The thin paste which is carried away is brought upon sieves of silk bolting-cloth, which are kept in constant motion. The starch passes through with the water as a milky fluid. This is allowed to settle when the water is drawn off. The starch is next treated with water containing a little alkali, the object of which is to dissolve gluten, oil, etc. The mixture is now brought into shallow, long wooden runs, where the starch is deposited, the alkaline water running off. Finally, the starch is washed with water, and dried at a low temperature.

Properties.—Starch in its usual condition is insoluble in water. If ground with cold water it is partly dissolved. If heated with water the membranes of the cells of which the starch is composed are broken, and the contents form a partial solution. On cooling, it forms a transparent

jelly called *starch-paste*. By dilute acids and ferments starch is converted into dextrin, maltose, and dextrose.

Flour.—Wheat flour, which may serve as an example of flour in general, contains water, starch with a little sugar and gum, *gluten*, and a small quantity of mineral matter. The finest flour contains about 10 per cent of gluten and 70 per cent of starch. Gluten is a substance that resembles in many respects the white of eggs, or egg-albumin.

Bread-making.—The chemical changes that take place in bread-making are of special interest. Bread is made by mixing the flour with water and a little yeast. The dough thus prepared is put in a warm place for a time, when it *rises*. The rising is a result of fermentation caused by the yeast. A part of the starch contained in the flour is converted into sugar, and this is then converted into alcohol and carbon dioxide by fermentation. In striving to escape from the thick gummy dough the carbon dioxide fills it with bubbles of gas, making it light and porous. When the loaf is put into the oven the gases contained in it expand, making it still lighter, and the alcohol passes off; then the fermentation is checked and no further chemical change takes place except on the surface where the substances are partly decomposed and converted into a dark-colored product, the crust.

A Few Compounds from Coal-tar.

Aromatic Compounds.—The fact that benzene, C_6H_6, toluene, C_7H_8, and other hydrocarbons are obtained from coal-tar has already been mentioned (p. 230). These hydrocarbons are the starting-points for the preparation of a large number of compounds of carbon that are com-

monly called the "aromatic compounds," as many of them have a pleasant aromatic odor.

Nitrobenzene, $C_6H_5NO_2$.—This substance is formed by treating benzene with nitric acid:

$$C_6H_6 + HNO_3 = C_6H_5NO_2 + H_2O.$$
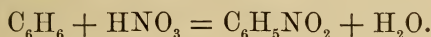
It is a yellow liquid with a pleasant odor like that of the oil of bitter almonds. It is much used under the name *artificial oil of bitter almonds.*

Aniline, $C_6H_5NH_2$.—When nitrobenzene is treated with nascent hydrogen the oxygen is extracted and hydrogen takes its place:

$$C_6H_5NO_2 + 6H = C_6H_5NH_2 + 2H_2O.$$
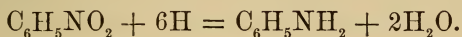
The product is the substance known as aniline. It is a colorless liquid. When treated with mercuric chloride (corrosive sublimate, $HgCl_2$) or arsenic acid commercial aniline is converted into the dye *magenta*, which is the substance from which the aniline dyes are prepared.

Aniline Dyes.—Of these a large number are in use. They are all derivatives of rosaniline, of which magenta is a salt. Aniline dyes of a great many different colors are made, some of them of great beauty.

Phenol, Carbolic Acid, C_6H_6O.—This familiar substance is contained in coal-tar, and is extracted from it by treating with caustic soda in which the carbolic acid dissolves. When pure it crystallizes in beautiful, colorless, rhombic needles. It has a peculiar, penetrating odor, and is poisonous. It is much used as a disinfectant.

Oil of Bitter Almonds,
Benzoic Aldehyde, $\Big\{$ C_7H_6O.—This substance occurs in combination in amygdalin, which is found in bitter

almonds, laurel-leaves, cherry-kernels, etc. Amygdalin belongs to the class of compounds known as *glucosides,* which break up into glucose and other substances. Amygdalin itself, under the influence of *emulsin,* which occurs with it in the plants, breaks up into oil of bitter almonds, hydrocyanic acid, and dextrose:

$$C_{20}H_{27}NO_{11} + 2H_2O = C_7H_6O + CNH + 2C_6H_{12}O_6.$$

Amygdalin.   Oil of   Hydrocy-   Glucose.
bitter   anic acid.
almonds.
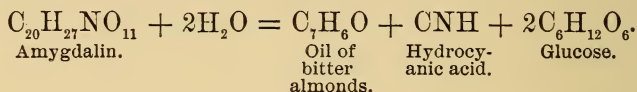
It is prepared from bitter almonds, which yield about 1.5 to 2 per cent. It is a liquid which has a pleasant odor. It is made artificially from coal-tar, and is used in the preparation of artificial indigo.

Benzoic Acid, $C_7H_6O_2$.—Benzoic acid occurs in gum benzoin and in the balsams of Peru and Tolu, and is made artificially from coal-tar by oxidizing toluene,* C_7H_8.

Balsams and Odoriferous Resins.—The balsams of Peru and Tolu are thick fragrant fluids that are obtained from certain trees in South America and elsewhere by cutting the bark. Benzoin is a similar substance. These as well as myrrh, frankincense, and other substances of the kind are used for their odors. The odors are increased when the substances are heated. Hence they are largely used as *incense.*

Gallic Acid, $C_7H_6O_5$.—Gallic acid occurs in sumach, in Chinese tea, and many other plants. It is formed by boiling tannin or tannic acid with sulphuric acid. It is prepared from gall-nuts by fermentation of the tannin

* The name toluene comes from the fact that this hydrocarbon was first obtained from the balsam of Tolu.

contained in them. It is closely related to tannin or tannic acid.

Tannic Acid, Tannin, $C_{14}H_{10}O_9$.—This substance occurs in gallnuts, from which it is extracted in large quantities. It is soluble in water. Its solution gives a dark blue-black color with iron salts. Tannin is used extensively in medicine, in dyeing, in the manufacture of leather and of ink.

EXPERIMENT 131.—Boil 10 grams of powdered gallnuts with 60 c.c. of water, adding water from time to time. A solution of tannin is thus obtained. Filter after standing. In a test-tube add to some of this solution a few drops of a solution of copperas (ferrous sulphate). A colored precipitate is formed which gradually changes to black.

Tanning.—The process of tanning consists in treating hides from which the hair has been removed with an infusion of hemlock or oak bark, or of sumach leaves, in which there is tannic acid. The acid combines with certain parts of the hides, forming insoluble compounds which remain in the pores, converting the hides into leather.

Indigo.—In several plants which grow in the East and West Indies, in South America, Egypt, and other warm countries, occurs a substance called *indican* which, when treated with dilute mineral acids and certain ferments, breaks up into indigo-blue and a substance resembling glucose. Commercial indigo contains as its principal ingredient indigo-blue. Indigo-blue is now prepared artificially.

Naphthalene, $C_{10}H_8$.—This is a hydrocarbon which is contained in coal-tar in large quantity. It is a beautiful white crystallized substance much used in the preparation

of dyes. The so-called "moth-balls" consist of naphthalene.

Anthracene, $C_{14}H_{10}$.—Anthracene like naphthalene is obtained from coal-tar. Its chief use is in the preparation of artificial alizarin.

Alizarin, $C_{14}H_8O_4$.—Alizarin is the well-known dye that was formerly obtained from madder-root. For some years it has been made artificially from anthracene, and the cultivation of madder has been largely given up. Madder-root was used for dyeing "Turkey red." Artificial alizarin is almost exclusively used for this purpose at present.

Glucosides.—Glucosides are certain natural substances that break down under the influence of ferments and dilute acids into sugar and other compounds. Amygdalin has already been mentioned. This breaks down into oil of bitter almonds and dextrose. Indican, which yields indigo and dextrose, is another example.

Myronic Acid, another glucoside, is found in the form of the potassium salt in black mustard-seed. When treated with myrosin, which is contained in the aqueous extract of white mustard-seed, potassium myronate is converted into dextrose and *oil of mustard*.

Alkaloids.—These are compounds occurring in plants, frequently being those parts of the plants that are most active when taken into the animal body. They are hence sometimes called the *active principles* of plants. Many of these substances are used in medicine. They all contain nitrogen and in some respects resemble ammonia. Only a few of the more important alkaloids need be mentioned here.

Quinine.—This valuable alkaloid is obtained from the outer bark of certain trees that grow in Peru.   The bark is known as Peruvian bark.

Cocaine is found in cocoa-leaves.   Its hydrochloric-acid salt has come into prominence in medicine, owing to the fact that a small quantity of its solution placed upon the eye or the gums or injected beneath the skin causes insensibility to pain.

Nicotine occurs in tobacco-leaves in combination with malic acid.

Morphine and **Narcotine** are the principal alkaloids found in *opium*, which is the evaporated sap that flows from incisions in the capsules of the white poppy before they are ripe.

QUESTIONS AND PROBLEMS.

CHAPTER I.

What two kinds of changes are you familiar with?

Give some familiar illustrations of each.

What is the chief difference between the two kinds of change?

Mention some examples of physical changes which are not given in the book.

Mention some examples of chemical changes not given in the book. Why do you call these changes chemical changes?

What is meant by saying that physical and chemical changes are related?

Give some familiar examples which make these relations clear.

How does the steam-engine illustrate these relations?

Suppose a stone should fall upon some gunpowder and cause it to explode, which would be physical and which chemical change?

Give some examples showing that heat can cause chemical changes.

Give some examples showing that chemical changes can produce heat.

Give examples showing that in some cases when substances are simply brought together chemical changes are caused.

Give some examples showing that solution aids chemical action.

How can we distinguish chemical action from all other kinds of action?

What is the difference between a mixture and a chemical compound?

How can this difference be illustrated by means of iron and sulphur?

Suppose sugar and sand were placed together in a vessel and well shaken up, would a chemical compound or a mechanical mixture be formed? Try the experiment, and see whether you can answer the question with the aid of the experiment. Treat the substance with water; what takes place? What is left?

When iron and sulphur combine chemically, is there any gain or loss in weight?

Explain the difference between elements and compounds.

Is wood an element? Why?

Is the number of compounds larger than the number of elements?

How many elements enter into the composition of the things with which we generally have to deal?

Give some examples of elements. Why are they called elements?

Give some examples of compounds. Why are they called compounds?

In general, what is meant by chemical action?

What three kinds of chemical action are there? Give examples of each.

Why does a stone fall to the earth when thrown upward?

Why do substances act chemically upon one another?

Suppose chemical attraction should cease, what would be the result?

Which of the elements is most abundant? Which comes next in order?

Which is the principal element that enters into the composition of living things?

How are the names of the elements formed? Give examples.

What is meant by the symbols of the elements?

CHAPTER II.

Describe the changes which are produced in lead, zinc, and tin by heating them, and describe the experiments which taught you what these changes are.

How did you learn that the air had anything to do with these changes?

Did heat have anything to do with the changes? Suppose you knew that the bits of metal used in Experiments 13, 14, and 15 increased in weight when heated in the air, and that they did not increase in weight when heated so that the air could not get at them, what would that show?

What familiar facts show that the air has something to do with burning?

How could you find out what the air does when things burn in it?

What is noticed when a candle is burned in a closed vessel?

When a candle burns is there a gain or loss of matter?

How much of the air is used up when anything burns in a closed vessel?

Suppose a substance is burned in a closed vessel containing air and gains 5 grams in weight, where would this 5 grams of matter come from? How much would you expect to find that the air had lost in weight?

What is the composition of the air?

Why are oxygen and nitrogen called elements?

CHAPTER III.

Where and in what quantity is oxygen found?

How can we get oxygen from the air?

Explain how oxygen is collected when it is set free from the oxide of mercury.

What other ways are there of getting oxygen?

What is the appearance of oxygen? Its smell? taste? What happens to it when it is much cooled down and compressed?

How does oxygen behave towards other substances at the ordinary temperature? How do you know this? Does oxygen act upon anything at the ordinary temperature? Give examples.

Of what importance is oxygen to all animals? What difference is there between the action of oxygen at the ordinary temperature and at higher temperatures? How did you learn this difference?

When substances burn in oxygen, is the oxygen used up? What becomes of it? Do the substances gain or lose in weight? How does the weight of the oxygen used up compare with the gain in weight of the substance burned?

What does burning in oxygen consist in?

Is burning in the air the same chemical act as burning in oxygen? How can this be proved? Why do substances not burn as actively in the air as they do in oxygen?

What is meant by combustion?

What are combustible substances?

What are incombustible substances?

Is water combustible? Is wood combustible?

Give an example of a substance which will not burn in the air, but which will burn in oxygen. How was this shown?

What is meant by the kindling temperature? Explain why it is that a stick of wood burns gradually and not all at once.

Explain the connection between the heat and light produced, and the combustion of a substance.

What is meant by the expressions *chemical work* and *chemical energy?*

Do combustible substances possess chemical energy?

Show how a combustible substance can do work. What are the substances called which are formed in combustion? Give examples.

CHAPTER IV.

Explain what is meant by saying that the elements combine in definite weights.

What is the law of definite proportions?

How are natural laws discovered?

What is a natural law?

In studying the proportions by weight in which the elements combine with one another, what is observed?

What are the combining weights of the elements?

How is a chemical compound expressed by a symbol?

What does the symbol NaCl mean? What does O stand for? What does Fe stand for?

How does a chemist express what takes place when mercury oxide is heated?

How much mercury is contained in 20 grams of mercury oxide?

How much oxygen is contained in 30 grams of mercury oxide?

How much mercury oxide would be necessary to furnish 10 grams of oxygen?

How much mercury oxide would be necessary to furnish 10 grams of mercury?

Explain what is meant by the law of multiple proportions. Give examples illustrating the law.

What do the symbols SO_2, CO_2, and H_2SO_4 mean ?

CHAPTER V.

Where and in what forms is nitrogen found in nature?

How can we get nitrogen from the air?

Why do we use phosphorus for the purpose?

Describe the method of preparing nitrogen.

How can nitrogen be obtained from the air by the use of copper?

What is the color of nitrogen? its taste? its odor? How does it differ from oxygen in its conduct towards burning things? Could animals live in it? Why? Suppose there were no nitrogen in the air, how would our fires differ from the fires in the air as it is now?

What is the difference between a chemical compound and a mechanical mixture?

Are nitrogen and oxygen chemically combined or mixed together in the air? What reasons can you give for your statement?

How is liquid air obtained?

How is oxygen obtained from it?

What is argon? Why was that name given to it?

CHAPTER VI.

How can it be shown that water is contained in wood? in meat?

Is water present in large or small proportion in animal and vegetable substances.

What is meant by water of crystallization?

What are efflorescent substances?

What are deliquescent substances?

Is water an element or a compound? How do you know?

Describe the experiment in which an electric current is passed through water. What does the experiment show?

CHAPTER VII.

Where and in what forms is hydrogen met with in nature?

How is hydrogen obtained?

What takes place when a piece of sodium is thrown upon water?

What takes place when steam is passed over heated iron?

What is water-gas, and how is it obtained?

Which are the common acids? What do they all contain? What takes place when they are treated with metallic elements?

What is the most convenient method for preparing hydrogen?

Describe the process fully, and show how you can collect the hydrogen.

How can it be purified?

What are the properties of hydrogen?

How is it shown that hydrogen is lighter than air?

What relation is there between the weights of equal volumes of hydrogen and oxygen?

If the weight of a certain bulk of hydrogen is 1 ounce, what would be the weight of the same bulk of oxygen?

What relation is there between the combining weights of hydrogen and oxygen and the weights of equal bulks of the two gases?

When we say that the combining weight of hydrogen is 1 and that of oxygen 16, what is meant? What is meant when we say the combining weight of iron is 56?

If we should call the combining weight of oxygen 100, what would be the combining weight of hydrogen?

What change takes place in hydrogen when it is cooled down very much and greatly compressed?

Does hydrogen combine with oxygen at the ordinary temperature? How do you know?

What takes place when it is heated in oxygen?

Does hydrogen support combustion? How can this be shown?

CHAPTER VIII.

What is formed when hydrogen burns? How can this be shown? How is it explained?

What takes place when a flame or spark is applied to a mixture of hydrogen and oxygen? How is this explained?

How can we show what takes place when a mixture of hydrogen and oxygen explodes? What has been shown to take place? How does this help us to understand what the composition of water is?

In what other way can the composition of water be found out?

Explain exactly how the experiment with copper oxide teaches us what the composition of water is.

What is meant by reduction? a reducing agent?

Explain the oxyhydrogen blowpipe and its uses.

Explain the lime-light or Drummond light.

Has water any color?

Is the water which is found in nature pure? Why is this?

Why does ice float on water?

What is the purest water found in nature? Why?

What is the character of the water found in mountain streams which flow over sand-stone? Why?

What is the character of the water which flows over limestone?

What are mineral springs?

How does water become salt?

What are effervescent waters? chalybeate waters? What is sulphur water?

What are the most common causes of impurities in water?

What change takes place in river-water which has been contaminated with sewage?

What precautions should be taken in regard to the position of wells? Why?

How can water be purified? Describe the process of distillation.

What kinds of substances cannot be removed from water by distillation?

What is meant by saying that water is the best solvent?

Why do we use solutions in studying the chemical action of substances upon one another?

What is a solution?

What is expressed by the symbol H_2O?

In what respects do hydrogen and oxygen resemble each other? In what respects do they differ from each other?

Do hydrogen and oxygen combine readily? Does combination take place more readily between those elements which are alike or between those which are unlike?

What change takes place in oxygen when electric sparks are passed through it? In what other ways can this change be brought about?

How can ozone be converted into oxygen?

When oxygen is changed to ozone, and ozone to oxygen, is there any change in weight?

What is hydrogen dioxide? How is it made? What is its most striking property? What is it used for?

CHAPTER IX.

What is destructive distillation?

From what kinds of substances is ammonia given off in destructive distillation?

What is one of the products formed when substances containing carbon, hydrogen, and oxygen are heated? In what experiment which you have already performed is this shown?

Explain why ammonia is formed in gas-works?

What does the process of decay consist in?

What becomes of the nitrogen contained in animal substances when they decay?

What connection is there between saltpetre and nitric acid? between potassium nitrite and nitrous acid?

What is the "ammoniacal liquor" of the gas-works? What is formed when hydrochloric acid is added to this liquor?

How is ammonia obtained from ammonium chloride?

Express what takes place in a chemical equation, and explain exactly what the equation means.

[The expression $2NH_4Cl$ represents twice the quantity of am-

monium chloride that is represented by NH_4Cl. So also $2NH_3$ represents a quantity of ammonia twice as great as that represented by NH_3.]

How much ammonia can be obtained from 50 grams of ammonium chloride?

The combining weight of nitrogen is 14, that of calcium, Ca, is 40, and that of chlorine, Cl, is 35.5. We have, therefore, these relations:

$$\begin{array}{ccccccccc}
2NH_4Cl & + & CaO & = & 2NH_3 & + & CaCl_2 & + & H_2O \\
2(14+4+35.5) & + & (40+16) & = & 2(14+3) & + & (40+71) & + & (2+16) \\
2 \times 53.5 & + & 56 & = & 2 \times 17 & + & 111 & + & 18 \\
107 & + & 56 & = & 34 & + & 111 & + & 18
\end{array}$$

To determine the quantity of ammonia which can be obtained from 50 grams of ammonium chloride, we have simply to solve the proportion

$$107 : 34 :: 50 : \text{the weight of ammonia.}$$

For from 107 parts by weight of ammonium chloride there are formed 34 parts by weight of ammonia, and, therefore, as these figures are to each other so is 50, the actual weight of ammonium chloride used, to the weight of ammonia obtained.

Describe the process of preparing ammonia from ammonium chloride. How is the gas collected? What is the appearance of ammonia? What is its odor? What effect does it produce upon breathing? What about its weight? How is this shown? Explain the use of ammonia for the purpose of making ice. Does ammonia burn? How does water act upon it?

What is " spirits of hartshorn "? " household ammonia "?

How is nitric acid formed in nature?

How is nitric acid obtained from saltpetre? Express in an equation what takes place. Describe the apparatus used, and give the reasons for the arrangement of the apparatus.

What is the appearance of pure nitric acid? What takes place when it is boiled? when the sun shines directly upon it?

What is ordinary commercial nitric acid? How is strong nitric acid made? How does strong nitric acid act? Why do substances burn in strong nitric acid? Describe some experiments which illustrate the power of nitric acid. What does the nitric acid give up to the substances upon which it acts?

What does nitric acid give up when a metallic element acts upon it? Describe what further takes place, and why.

What is *aqua regia*, and why has it received this name?

What compounds does nitrogen form with oxygen? How does this series illustrate the law of multiple proportions? What is the law of multiple proportions?

How is nitrous oxide formed? How is it usually prepared? Give the equation representing the action, and state what it means.

What are the properties of nitrous oxide? its uses?

How is nitric oxide made? What takes place when it is brought in contact with the air? Why is the gas red which first appears in the flask used in making nitric oxide? and why does it afterwards become colorless? Give the equations which represent what takes place when nitric acid acts upon copper, and explain what they mean.

How is nitrogen peroxide formed? What are its chief properties? For what is it used?

CHAPTER X.

What is meant by saying that oxygen belongs to a family of elements?

In what form does chlorine occur in nature? in what quantity? What are all the chlorine compounds with which we have to deal made from?

What two steps are necessary in order to get chlorine out of sodium chloride or common salt? What resemblance is there between the process for making hydrochloric acid from common salt and that of making nitric acid from sodium nitrate? What is formed besides hydrochloric acid and nitric acid in each case?

How is chlorine made in the laboratory? Why is this method not well adapted to the commercial manufacture of chlorine?

Describe Deacon's process for the manufacture of chlorine.

Describe Weldon's process for the manufacture of chlorine.

Describe the electrolytic process for the manufacture of chlorine.

Describe accurately the method of making chlorine used in the laboratory. How is the chlorine collected? What takes place when powdered antimony is introduced into chlorine? copper foil? flowers and calico?

What is the appearance of chlorine? its odor? its action upon the throat and nose? Is it heavier or lighter than air? What is its action upon water? What is bleaching?

What is disinfection? What is " bleaching-powder "? What other name has it? Why is it valuable as a disinfecting agent?

Compare the action of hydrogen on oxygen and on chlorine. What are the products? What are chlorides?

What is the simplest way of forming hydrochloric acid? What difference is there between the action of a mixture of chlorine and hydrogen and a mixture of hydrogen and oxygen? What art is dependent upon chemical changes caused by light? Describe the method of preparing hydrochloric acid. Give the equation expressing the action, and state what it means.

If 40 grams of common salt are used, how much hydrochloric acid and how much sodium sulphate will be obtained?

How is the hydrochloric acid collected? What are the properties of hydrochloric acid? Give a connected account of all that you learned about it in Experiment 65. How can the composition of hydrochloric acid be determined? What is the composition? What happens to hydrochloric acid when it is treated with a

metallic element like zinc? when treated with an oxide like zinc oxide? When treated with substances which give up oxygen readily?

How are the chief compounds of chlorine hydrogen, and oxygen obtained? What is potassium chloride? potassium hypochlorite? potassium chlorate? What takes place when these compounds are treated with sulphuric acid? Express the reactions by equations, and show how the reactions resemble one another. Compare the reactions with that which takes place when sulphuric acid acts upon sodium or potassium nitrate.

To which of the substances above mentioned is " bleaching-powder " allied?

In what way does the series of compounds of chlorine with hydrogen and oxygen illustrate the law of multiple proportions?

CHAPTER XI.

What takes place when an acid and a base are brought together?

What are alkalies? Mention some common acids; some common bases. How can you conveniently tell whether a substance is an acid or a base?

What did you learn in Experiments 66 and 67?

How can you determine what is formed when an acid acts upon a base? What is formed when hydrochloric acid acts upon caustic soda? nitric acid upon caustic soda? sulphuric acid upon caustic soda? hydrochloric acid upon caustic potash? nitric acid upon caustic potash? sulphuric acid upon caustic potash?

What do the experiments performed teach in regard to the action of acids upon bases?

What is formed when a metallic element acts upon an acid?

What is an acid? a base? a salt?

What is a metal?

Of what importance is water in these reactions?

What is solution? What kinds of solutions are there? What are electrolytes? non-electrolytes? What are ions? How do acids, bases, and salts dissociate in solution? Upon what does the extent of electrolytic dissociation depend?

What is the difference between ions and atoms?

Define acids and bases in terms of the theory of electrolytic dissociation.

What is " hydroxyl "?

Explain neutralization in terms of the theory.

Explain the use of the syllables *ic* and *ous* in naming acids; of *hypo* and *per*. Give the names and symbols of the compounds of chlorine, hydrogen, and oxygen.

How are bases named?

Explain how salts are named. What is the name and formula of the potassium salt of hypochlorous acid? of perchloric acid? of chloric acid? of nitric acid?

What are the salts of hydrochloric acid called? Why?

What connection is there between acid properties and oxygen?

CHAPTER XII.

What takes place when animal and vegetable substances are heated to a high temperature? Why is this? What takes place when they are heated in the air?

Give a familiar example of the process of destructive distillation. For what purpose is coal distilled? wood?

What are the principal forms in which carbon occurs in nature? Mention some of the most common compounds of carbon.

What two forms of pure carbon are there?

Where are diamonds found, and what is the general appearance of a diamond when first found? How have diamonds been made artificially?

How can graphite be made? Compare graphite and diamond, stating the properties of each. By what other names is graphite known? What are its uses?

What is amorphous carbon?

Describe the process by which charcoal is made.

Compare the properties of charcoal with those of diamond and graphite.

What is coke, and how is it obtained? lamp-black? bone-black or animal charcoal?

What are charcoal filters used for? What are bone-black filters used for?

What is the object of charring piles which are exposed to the action of air and water?

What different kinds of coal do we distinguish between? What is lignite? peat?

How was coal formed?

What are the chief products of the destructive distillation of coal? Are hard or soft coals used in the manufacture of illuminating-gas? Why?

How can it be proved that diamond, graphite, and charcoal consist only of the element carbon? What common properties have the different forms of carbon?

What is meant by the name allotropy?

How can we form an idea in regard to the reason why one and the same thing can appear in different forms?

Compare the chemical conduct of carbon with that of the other elements thus far considered.

What is formed when carbon combines directly with oxygen? How can this be proved? How can we easily recognize carbon dioxide?

Explain what takes place when a mixture of charcoal and copper oxide is heated; when a mixture of white arsenic and charcoal is heated. Is there any resemblance between the action of hydrogen and of charcoal on heated copper oxide?

Why is carbon called a reducing agent?

What important use is made of charcoal as a reducing agent?

CHAPTER XIII.

What are hydrocarbons? Are these easily formed in the laboratory? Under what circumstances are they easily and abundantly formed?

What is petroleum? Why must it be refined before it is fit for use in lamps? How is it refined? What is the product called?

What are some of the light products obtained when petroleum is refined? What is paraffin?

Give the names and symbols of the four simplest hydrocarbons contained in petroleum.

What is meant by homology, and an homologous series?

Give the names and symbols of the first three members of the ethylene series.

Give the names and symbols of the first two members of the acetylene series.

Give the names of the first three members of the benzene series.

Where is marsh-gas found, and under what circumstances is it formed? What are the final products of the oxidation of vegetable matter? What is the chief product of the reduction of vegetable matter?

Of what importance is the occurrence of marsh-gas in coal-mines?

How is marsh-gas made in the laboratory?

What are the properties of marsh-gas?

How is ethylene obtained, and what are its properties? What other name has it?

How is acetylene formed, and what are its properties?

Describe in brief the method of making coal-gas.

What is coal-tar? Mention some of the products obtained from it.

What is the principal compound of carbon and oxygen?

Where and in what forms is carbon dioxide found?

What processes which are constantly taking place give rise to the formation of carbon dioxide?

How is carbon dioxide most easily made? Describe the process accurately. Express the action by means of a chemical equation, and state what it means.

What are the properties of carbon dioxide?

Why does not carbon dioxide burn?

What is meant by the statement, " Carbon can do chemical work "? What resemblance is there between a piece of carbon and an elevated body of water?

What is soda-water, and how is it made?

What connection is there between the breathing process and carbon dioxide? Is carbon dioxide poisonous?

Why is the air in badly ventilated rooms injurious?

Why is carbon dioxide apt to be found in old wells? How can it be detected if present in large quantity?

What is choke-damp, and what does the name come from?

Of what importance to plants is the carbon dioxide in the air?

Of what importance is it to animals? What resemblance is there between the food of animals and the fuel burned in· stoves?

How does the carbon of animals and plants get back into the air again?

In what way is all life directly dependent upon the sun?

How are carbonates formed? What is the composition of sodium carbonate? of potassium carbonate? What, then, is the composition of carbonic acid? What takes place when carbonic acid is set free from carbonates?

What takes place when carbon dioxide acts upon potassium hy- droxide? upon calcium hydroxide? Give the equations represent- ing the action, and name the products.

What takes place when carbon dioxide is passed into lime- water until no further action is observed? What change occurs when the solution thus obtained is boiled?

What are hard waters? How are they formed? Why do we make the distinction between temporary and permanent hard- ness? What objection is there to hard waters?

How is carbon monoxide formed? Explain its formation in open grate fires. What is the blue flame at the top of a coal fire due to?

Why is the use of water-gas sometimes objected to?

How is carbon monoxide made? What are its properties?

What danger is there connected with the use of coal stoves? Why is smouldering charcoal a dangerous thing to have in a room?

Why is carbon monoxide a good reducing agent?

Of what importance is it in the reduction of iron from its ores?

What is a flame? What is the difference between a candle and a lamp?

How can it be shown that when a burning gas is cooled down it is extinguished?

Explain the construction of the miner's safety lamp, and the reason for its use.

Why do some flames give light and others not?

How are cyanides formed? What is yellow prussiate of potash, and how is it made? What is potassium cyanide? How is cyanogen made? What are its properties?

Where is prussic acid found? How is it made? What are its properties?

CHAPTER XIV.

What are the two principal laws governing chemical action?

Do we know why substances combine according to the laws of definite and multiple proportions?

What is an hypothesis? a theory?

What theory has been suggested to explain the laws of definite and multiple proportions?

Show how this theory accounts for the facts.

What is meant by the atomic weights?

What is meant by the expression molecule?

What are the symbols of the elements intended to represent? the symbols of compounds?

Explain in full what the symbols HNO_3, H_2SO_4, NH_3, CH_4, and CO_2 are intended to represent? What relation is there between the weight of a molecule and the weights of the atoms of which it is made up?

What is Avogadro's hypothesis?

How does Avogadro's hypothesis help us to determine the relative weights of the molecules of gaseous subtances?

How are the atomic weights determined from the molecular weights?

What difference is there between chlorine, oxygen, nitrogen, and carbon as shown by the symbols of their compounds with hydrogen? What is meant by the valence of an element?

What is meant by a univalent element? a bivalent element? a trivalent element? a quadrivalent element? Barium forms the compound $BaCl_2$; what is the valence of barium? Sodium forms the compound $NaCl$; what is the valence of sodium?

In the formation of potassium nitrate from nitric acid, how is the valence of potassium shown? When a bivalent element like calcium forms a salt with nitric acid, how does the displacement of hydrogen take place? Calcium is bivalent. What is the symbol of its salt with sulphuric acid? Explain this. What is the symbol of the sodium salt of sulphuric acid? What does this show with regard to the valence of sodium?

If magnesium, Mg, is bivalent, what is the symbol of its sulphate? of its nitrate? of its chloride? of its oxide?

What is the basis for the distinction between acid-forming and base-forming elements? Give examples of the two classes. What are these classes sometimes called?

What is meant when we speak of a family of elements?

What are the families of acid-forming elements?

CHAPTER XV.

Name the members of the chlorine family.

Why is fluorine included in this family?

In what forms does bromine occur in nature?

How is bromine obtained from sodium bromide? Give the equations representing the steps which must be taken, and explain what is meant by them.

What are the properties of bromine? What are the chief differences between bromine and chlorine?

What is hydrobromic acid, and how is it formed? What difference is there in the conduct of common salt and of potassium bromide towards sulphuric acid? How is this explained?

What compounds does bromine form with hydrogen and oxygen?

In what forms does iodine occur in nature? How is it obtained in Scotland and France? What is kelp?

How is iodine obtained from sodium iodide? Give the equations representing the action, and explain what they mean.

What are the properties of iodine? Compare chlorine, bromine, and iodine, stating the points of resemblance and difference.

How can you easily tell whether a subtsance is an iodide or not? Why does not potassium iodide turn starch-paste blue?

How is hydriodic acid obtained? How does it differ from hydrochloric and hydrobromic acids? What takes place when potassium iodide is treated with sulphuric acid?

In what forms does fluorine principally occur in nature? How is it obtained? What are its properties?

How is hydrofluoric acid made, and what are its properties? Give the equation representing the action of sulphuric acid on fluor spar? What use is made of hydrofluoric acid? Can the substance be kept in glass bottles?

What analogy is there between chlorine, bromine, and iodine, as far as the compounds which they form are concerned?

What relation is there between the atomic weights of chlorine, bromine, and iodine?

CHAPTER XVI.

Name the members of the sulphur family. Why has sulphur been known for a long time? Where is it found in nature? What is the chief source of the sulphur of commerce? Name some of the principal compounds in which sulphur occurs in nature.

Describe the process by which sulphur is extracted from its ores.

How is crude brimstone refined? What is the difference between "flowers of sulphur" and "stick sulphur"? Give the properties of sulphur. What changes does it undergo when it is distilled?

In what two forms can sulphur be obtained? How can it be thus obtained? How do the two forms differ from each other?

How does sulphur act when heated in the air?

What are sulphides? How are they formed?

Can sulphur and hydrogen be made to combine directly? What is formed? Where is this compound found in nature? Under what conditions is it formed?

How is hydrogen sulphide made in the laboratory? Explain what takes place when sulphuric acid is used; when hydrochloric acid is used. How is the substance collected? What are its properties? How does it behave towards water? towards metals? What takes place when it is passed over heated iron? Is there any resemblance between this action and that which takes place

when steam is passed over heated iron? Express both acts by chemical equations.

What takes place when hydrogen sulphide is passed through solutions containing metals in the form of soluble salts?

How can hydrogen sulphide be used in chemical analysis?

What is formed when sulphur is burned in the air? What is formed when sulphur dioxide takes up more oxygen? What is the product of the action of sulphur trioxide on water? What relation is there between sulphurous acid and sulphuric acid?

Where is sulphur dioxide found in nature? How is it made in the laboratory? Explain the reactions, giving the equations.

What are the properties of sulphur dioxide? What uses are made of sulphur dioxide?

How are sulphites made? What is the composition of sodium sulphite? What takes place when sodium sulphite is treated with sulphuric acid? with hydrochloric acid? Compare these reactions with those which take place when sodium carbonate, Na_2CO_3, is treated with sulphuric acid and with hydrochloric acid.

Mention some salts of sulphuric acid which are found in nature. How is sulphuric acid made? Explain the action of nitric oxide in oxidizing sulphurous acid.

Describe the manufacture of sulphuric acid. Describe the arrangement of a leaden chamber.

What is oil of vitriol, and how is it obtained? How does sulphuric acid act upon sodium chloride? upon potassium nitrate?

How does sulphuric acid act towards water? How does it act upon organic substances which contain hydrogen and oxygen? What change does it produce in wood? Explain the change.

Of what importance is sulphuric acid in the arts?

What marked difference in conduct is there between sulphuric acid and hydrochloric and nitric acids?

What is a monobasic acid? a dibasic acid?

Define acid, normal, and neutral salts.

What is carbon bisulphide? How is it made, and what are its properties?

Why are selenium and tellurium included in the sulphur family?

What relation is there between the atomic weights of sulphur, selenium, and tellurium? Has any similar relation been noticed in the case of other elements?

CHAPTER XVII.

How does phosphorus occur in nature? What is a phosphate? How is phosphorus made?

What are the properties of phosphorus?

Explain what takes place when phosphorus and iodine are brought in contact with each other.

What is red phosphorus? How is it made from ordinary phosphorus? Compare the two varieties of phosphorus. How is ordinary phosphorus made from red phosphorus?

Describe the changes which take place when phosphorus is burned in the air or in oxygen, and the product dissolved in water.

How is ordinary phosphoric acid made? What salts does it form with sodium? What is normal calcium phosphate? Why is phosphoric acid called a tribasic acid?

In what compounds is the element arsenic found in nature? What are its properties?

What compound does arsenic form with hydrogen? What compound of nitrogen is it analogous to? How is it formed? Explain all that takes place in Experiments 99 and 100.

What are the properties of arsine?

What is the substance which is usually called arsenic? How is it obtained from the element arsenic, and from the compounds of arsenic with metals? What are its properties?

Explain what takes place when arsenic trioxide and charcoal are mixed together and the mixture heated.

In what form does antimony chiefly occur in nature? What are its general properties?

Compare stibine and arsine.

In what forms does boron occur in nature? How is it prepared? What are its properties?

What is borax, and from what acid is it derived?

Mention some of the principal compounds of silicon which occur in nature. Is it a rare or common element? What other element does it resemble in some respects?

Does silicon occur in nature in the uncombined state? How is the element obtained?

Mention some of the varieties of silicic acid, and point out the relation which exists between them.

Mention some of the principal varieties of silicon dioxide which occur in nature.

What important manufactured product contains silicon?

CHAPTER XVIII.

What is meant by the name base-forming elements? What name is given to the elements which are not base-forming elements? How does the number of base-forming elements compare with the number of acid-forming elements?

What is meant by metallic properties?

What are the chief classes of metal derivatives?

What are minerals?

What is meant by the term metallurgy?

CHAPTER XIX.

What are the alkalies, and why are they so called?

In what form is potassium found in nature? Of what importance is the element potassium to plants? Where does the potassium which the plants use come from? What is left when wood is

burned? Suppose you wanted potassium sulphate, and had only wood ashes and sulphuric acid, how could you get it?

In what other forms besides those mentioned, does potassium occur in nature?

How is potassium obtained from its compounds? What are its properties? Explain what takes place when potassium acts upon water.

How is potassium iodide made? Explain the reactions. What takes place when potassium iodide is treated with sulphuric acid? What is potassium iodide used for?

How is potassium hydroxide formed? What is its common name? Explain the reaction which is used in making potassium hydroxide. What are the properties of the hydroxide? What change does it undergo when exposed to the air?

Where is saltpetre found, and under what conditions is it formed?

Describe the saltpetre plantations. How is saltpetre used in making sulphuric acid? How is it used in making nitric acid?

Give an account of the manufacture of gunpowder, and explain why it acts as an explosive.

In what form is sodium found in nature? What are its properties? How does it differ from potassium?

What is meant by saying that sodium is a good reducing agent? What is sodium amalgam, and for what is it used?

Where and in what quantities is sodium chloride found?

How is salt obtained from natural sources?

What are the properties of sodium chloride?

What are the chief uses of salt?

What is caustic soda, and how is it obtained?

Where is sodium nitrate found? Why can it not be used in making gunpowder? How can potassium nitrate be made from it?

What is the common name of sodium sulphate? In what important manufacturing process is it obtained? What percentage of water of crystallization does it contain? What change takes place in it when it is left in contact with the air? Is it deliquescent or efflorescent?

Of what importance is sodium carbonate? From what source was it formerly obtained?

How did Leblanc come to devise a method for making sodium carbonate?

Describe Leblanc's process.

Describe the Solvay process.

What percentage of water of crystallization does sodium carbonate contain?

What relation does bicarbonate of soda bear to sodium carbonate? How is it made? Explain its use in baking-powders.

What is the substance which is commonly called phosphate of soda?

What is the composition of borax? Where is it found in nature? What change takes place in borax when it is heated? Explain the use of borax in soldering. What is meant by saying that borax is an antiseptic?

What is water-glass, and how is it made? What is it used for?

What action takes place when ammonia is brought together with acids? What are the products when hydrochloric, nitric, and sulphuric acids are treated with ammonia? Why are these substances included among the derivatives of the potassium family? What is the difference between ammonia and ammonium?

What is sal ammoniac, and how is it chiefly obtained? Give the equations expressing the reactions which take place when sal ammoniac is treated with caustic soda and with quick-lime.

How is ammonium sulphide made, and what is its composition?

What relation exists between the atomic weights of the alkali metals?

What are flame reactions, and how are they used for the purpose of detecting substances?

How can potassium and sodium be detected when both are present?

What is a spectrum? How can the spectrum of a light be used for telling what substances are in the flame?

What are the principal parts of the spectroscope? Of what service has it been to chemistry?

Tell about the discovery of helium.

CHAPTER XX.

Mention some of the chief compounds of calcium found in nature. Of what interest is calcium chloride? How is it made?

What is lime? How is it made? Explain a lime-kiln. Explain the use of lime in making the lime-light. What change takes place when lime is left exposed to the air? What change takes place in it when it is treated with water? What is lime-water?

What changes are produced in lime-water by passing carbon dioxide into it?

What is calcium carbide? How is it made? For what purpose is it used?

What is bleaching-powder, and how is it made? Of what value is bleaching-powder? Under what conditions does it give up its chlorine?

Mention some of the principal varieties of calcium carbonate which are found in nature. What are stalagmites and stalactites?

What is gypsum? Explain the use of plaster of Paris.

Explain the difference between permanent and temporary hardness of water.

How can temporary hardness be remedied? How can permanent hardness be remedied? Explain the action in each case.

What application is made of gypsum?

What forms of calcium phosphate are found in nature? What is meant by the name normal calcium phosphate?

Of what importance is calcium phosphate to plants? What objection is there to the use of normal calcium phosphate as a fertilizer? What is superphosphate of lime, how is it made, and what is it used for?

How is mortar made? Why do freshly plastered rooms remain moist so long? How can the process of drying be hastened?

What is common glass? What is the difference between common glass and Bohemian glass? What is flint-glass, and for what is it used?

How is colored glass made?

Explain how barium dioxide is used for extracting oxygen from the air. How is it used in making hydrogen dioxide?

What flame reactions do calcium compounds give? strontium compounds? barium compounds?

What relation exists between the atomic weights of calcium, strontium, and barium?

CHAPTER XXI.

Mention the chief compounds of magnesium which are found in nature.

How is magnesium prepared? What are its most striking properties?

What is magnesia? What change does water effect when brought in contact with magnesia?

Mention the chief forms in which zinc is found in nature.

How is zinc obtained from its ores?

What are the most striking properties of zinc?

What is galvanized iron? brass? German silver?

Explain what takes place when zinc is heated to a high temperature in the air.

What is zinc-white? What advantage has it over white lead?

What is white vitriol? In what experiments which you have performed has it been obtained? How is it made on the large scale? What are the final products of roasting zinc sulphide?

Where and in what form does copper chiefly occur in nature? What is the substance known as copper pyrites?

What takes place when an oxide of copper is heated with charcoal? Explain the reaction.

What are the most striking properties of copper? What takes place when it is heated with nitric acid? with sulphuric acid?

Explain the process of copper-plating.

What are alloys? What is brass? bell-metal? bronze?

What is the difference in composition between cuprous and cupric compounds? Give examples.

What is the composition of cuprous oxide, and what is the name of that variety of it which occurs in nature?

How is copper oxide made? Explain what takes place when a solution of caustic soda is added to a cold solution of copper sulphate? What change takes place on boiling?

What is the most common salt of copper? What effect does heating produce upon the substance?

In what forms does mercury occur in nature? How is it obtained from its chief compound? Why are mercury thermometers of no value in arctic regions?

What are the alloys of mercury called? Why are the zinc plates in galvanic batteries amalgamated?

How is mercuric oxide formed? For what has it been used in experiments which you have performed?

What is calomel, and how is it obtained? For what is it used?

What is corrosive sublimate, and how is it manufactured? What objection would there be to having a little corrosive sublimate mixed with the calomel which is used in medicine?

In what form does silver occur in nature? Explain how silver is extracted from galenite: (1) by Pattinson's process; (2) by Parker's method; (3) by the amalgamation process.

What action do air and water have upon silver? Why do silver coins, etc., carried in the pockets become dark-colored? Why do silver spoons used in eating eggs become tarnished? (see near the bottom of page 153.)

Why is not pure silver used in making coins? What is used?

How is silver-plating accomplished? How are mirrors made?

How is silver nitrate made? Why is this salt used in making indelible inks? How can stains made by silver nitrate be removed?

Explain all the chemical processes made use of in Experiment 117, for the purpose of making pure silver nitrate from a silver coin. What change takes place in silver chloride when it is exposed to the light? in silver bromide? in the iodide?

What example have we already had to deal with which showed that light can produce chemical changes?

Explain in brief the chemical changes upon which the art of photography is based.

CHAPTER XXII.

Mention some of the principal compounds of aluminium which occur in nature.

How is aluminium made?

What are the most important properties of aluminium? How does its weight compare with that of the metals in common use? What advantage does it possess over iron?

What is aluminium bronze, and how is it made? How is aluminium used in welding?

What are the forms of aluminium oxide found in nature? How can the oxide be made in the laboratory?

What is ordinary alum? What are the alums? Give examples. What relation do they bear to sulphuric acid?

What uses are made of alum?

What is the principal silicate containing aluminium? How does the element potassium get into the soil? Where does clay come from? Would you expect to find loose soil mostly on the tops of mountains or in valleys? Why? What is kaolin?

What is porcelain? Explain the process of glazing.

What is ultramarine, and how is it made?

Mention the chief compounds of iron which are found in nature. Where is iron found in the uncombined state?

Explain the process of extracting iron from its ores. What is a flux? What is slag?

What is pig-iron? cast-iron? wrought-iron? How is cast-iron converted into wrought-iron? What is steel? How is steel made?

What are the properties of pure iron? Explain the change which iron undergoes in moist air. What is given off when iron is dissolved in hydrochloric acid?

What is the difference in composition between the ferrous and ferric compounds? Give the formulas of ferrous and ferric sulphates, ferrous and ferric oxides. How could we decide whether the formula $FeCl_2$ or Fe_2Cl_4 is the correct one for ferrous chloride?

How are ferrous compounds converted into ferric compounds? Why is the change hastened by adding nitric acid?

How is ferrous chloride made? Explain the changes which take place when caustic soda is added to its solution, and the mixture is allowed to stand in contact with the air; when the solution is boiled with a few drops of nitric acid. How can ferric chloride be converted into ferrous chloride?

What is copperas, and what other names has it? What is it used for? What are some of the different kinds of ink?

Compare the formula of iron-alum with that of ordinary alum.

What is the principal variety of ferric oxide? What is rouge, and how is it made? What is the composition of loadstone? Under what circumstances is this oxide formed?

How is ferrous sulphide made? For what has it been used in experiments already performed?

What is iron pyrites? What changes take place in it when it is heated in an open vessel?

In what forms is nickel found in nature? Why is nickel used for plating other metals and for making coins?

In what forms is cobalt found in nature? What are cobalt compounds principally used for? What is smalt? What is cobalt ultramarine?

CHAPTER XXIII.

What is the chief compound of manganese found in nature? What other compounds with oxygen does manganese form?

What is the chief natural compound of chromium?

What is potassium chromate, and how is it made? What is potassium bichromate, and how is it made? Explain the relation which exists between potassium chromate and potassium bichromate. How is potassium bichromate converted into potassium chromate?

What takes place when potassium chromate or bichromate is treated with hydrochloric acid?

What is chrome-yellow? How is it made?

What is chrome-alum? Explain its relation to the other alums which have been mentioned.

In what form does the element uranium occur in nature?

In what form does bismuth occur in nature, and how is it obtained from its ores?

What is fusible metal? Wood's metal?

What is formed when bismuth is burned in the air?

What is the chief salt of bismuth?

CHAPTER XXIV.

In what compounds does lead occur in nature?

How is lead extracted from its ores?

What are the chief properties of lead? Explain the formation of the "Arbor Saturni."

What objection is there to the use of lead pipes for conveying water for drinking purposes?

What compounds does lead form with oxygen? What takes place when lead is heated in the air?

What advantage is taken of this fact in separating lead and silver?

What is red lead? What other name has it? What change does nitric acid effect in it?

What is lead peroxide? What is formed when hydrochloric acid acts upon lead peroxide?

How could you get the sulphate, chloride, and chromate of lead?

What is white lead? Why does white lead turn black and zinc-white not?

In what form does tin chiefly occur in nature? How is the metal obtained from the ore?

What is tin-foil? What effect does air have on tin at the ordinary temperatures? What effect does nitric acid produce on tin?

What is tin-ware? What danger is there in the use of inferior tin-ware? What are pins made of?

What is solder? britannia? bronze? bell-metal? Explain the process of soldering. What objection is there to the use of solder in closing tin cans containing things which are to be eaten?

What is the difference in composition between stannous and stannic compounds?

What is tin salt? What is it used for? What is mosaic gold?

In what form does platinum occur in nature? Where is it chiefly found? How is it obtained from its ores?

What are the most striking properties of platinum?

For what purposes is platinum used?

In what form does gold occur in nature?

How is it usually extracted from its ores?

What are its most striking properties?

Why is not pure gold used in making gold ware and coins? What is 20-carat gold? What is the composition of the standard gold coin of the United States?

CHAPTER XXV.

What was the first meaning of the name organic chemistry? inorganic chemistry? What does organic chemistry mean now?

Mention some of the principal forms in which carbon occurs in nature?

What takes place when coal is distilled?

What takes place when wood is distilled?

What takes place when bones are distilled?

What is meant in general by fermentation? What is the best known example of fermentation?

Mention some of the principal classes of compounds of carbon.

How is methyl alcohol formed? What other name has it? What are its chief properties?

How is ordinary alcohol made? Explain what took place in Experiment 127.

What change takes place in sugar when it undergoes fermentation? What causes the change in the sugar? Why do fruit-juices lose their sweetness when exposed to the air?

Mention some other kinds of fermentation besides alcoholic fermentation.

How is alcohol obtained from fermented liquids? What is fusel oil?

What are the chief properties of ethyl alcohol?

What are the chief uses of alcohol?

What is glycerin? How is it obtained? What are its chief properties?

What is formic acid, and where is it found in nature? What are its chief properties?

What is acetic acid? What is "mother of vinegar"? How is acetic acid made? Whence come the names pyroligneous acid and wood-vinegar?

What are the chief properties of acetic acid? For what purposes is it used? What are the principal salts of acetic acid?

What are the fatty acids? Mention some of the principal fatty acids. What is such a series as that of the fatty acids called?

Of what interest is butyric acid? palmitic acid? stearic acid?

What are soaps? How are they made? How does soap act in washing?

What happens when soap is added to a hard water? Why do the hands feel sticky when we attempt to wash them in hard water?

What connection is there between soap and civilization? How is soft-soap made? What connection is there between the manufacture of sulphuric acid and sodium carbonate and that of soap?

What is the composition of oxalic acid? Where and in what form is it found in nature? How is it manufactured? For what is it used?

What is the composition of lactic acid? How is it formed?

Where is malic acid found in nature?

Where is tartaric acid found in nature? What is "cream of tartar," and under what circumstances is it formed?

Where is citric acid found in nature? How is it prepared?

What is ordinary ether? How is it made?

What is meant by the word anæsthetic?

What is the action of an alcohol upon an acid? What is the product called? What class of substances do the alcohols act like? Compare the action of nitric acid upon alcohol and upon caustic potash.

What is meant by saponification?

What are fats? Explain what takes place when fats are treated with an alkali.

What does butter consist of? oleo-margarin?

What connection is there between the flavors of fruits and ethereal salts?

What is nitroglycerin? To what class of substances does it belong? What is dynamite?

What relations exist between the hydrocarbons of the marsh-gas series and the simplest alcohols and acids?

What is an alcohol?

What similarity is there between aluminium hydroxide and glycerin?

What is meant by the expression radical or residue?

What common acid are the organic acids related to?

CHAPTER XXVI.

What are the carbohydrates?

Where is dextrose found? What other names has it?

How is dextrose formed? What relation exists between it and cane-sugar? between it and starch?

Describe the process used in the manufacture of glucose.

What are the chief properties of glucose? How does it differ from cane-sugar? How can alcohol be obtained from it? How lactic acid?

What is fructose? What relation exists between it and cane-sugar?

Where is cane-sugar found in nature?

Describe the process of sugar-refining.

What is molasses? What are the chief properties of sugar? What is caramel? invert-sugar? What is the action of yeast upon cane-sugar?

What is sugar of milk? What are the constituents of cow's milk? How is cheese made? What is it? How is sugar of milk obtained from milk? What does the process of souring of milk consist in?

Of what importance is cellulose in the vegetable kingdom? What takes place when cellulose is treated with concentrated sulphuric acid and boiled? What is gun-cotton? collodion? What

is collodion used for? What is celluloid? What is paper? Describe the process of paper-making.

In what forms is starch found in nature? Describe the manufacture of starch. What is starch-paste? What change is effected in starch by dilute acids and ferments?

What are the chief constituents of flour?

What causes bread to rise?

What is meant by the name "aromatic compounds"?

What is nitrobenzene, and how is it made?

How is aniline made? What is magenta? What are the aniline dyes?

What is carbolic acid?

What is the oil of bitter almonds? Where is it found in nature? What is it used for?

What is the source of benzoic acid? What are balsams? Give some examples.

Where is gallic acid found? How is it prepared?

Where does tannic acid occur? For what is it used?

What does the process of tanning consist in?

In what form and where does indigo occur in nature?

What is naphthalene? anthracene? What is the chief use of anthracene?

What is alizarin? How is it made?

What are the glucosides? What examples have already been mentioned? Of what importance is myronic acid?

What are the alkaloids? What simple inorganic compound do they resemble? What is the source of quinine? cocaine? nicotine? morphine and narcotine?

INDEX.

WEIGHTS AND MEASURES.

ENGLISH SYSTEM.

Troy or Apothecaries' Weight.

Pound.		Ounces.		Drams.		Scruples.		Grains.		Grams.
1	=	12	=	96	=	288	=	5760	=	372.96
		1	=	8	=	24	=	480	=	31.08
				1	=	3	=	60	=	3.885
						1	=	20	=	1.295
								1	=	0.0647

Avoirdupois Weight.

Pound.		Ounces.		Drams.		Grains.		Grams.
1	=	16	=	256	=	7000	=	453.25
		1	=	16	=	437.5	=	28.328
				1	=	27.343	=	1.77
						1	=	0.0647

Imperial Measure.

Gallon.		Pints.		Fl. Ounces.		Fl. Drams.		Minims.		Cubic Centimeters.
1	=	8	=	160	=	1280	=	76800	=	4545.86
		1	=	20	=	160	=	9600	=	568.23
				1	=	8	=	480	=	28.41
						1	=	60	=	3.55
								1 cubic inch	=	16.383

METRIC SYSTEM.

Measures of Length.

Meter.		Decimeters.		Centimeters.		Millimeters.		Inches.
1	=	10	=	100	=	1000	=	39.37100
		1	=	10	=	100	=	3.93710
				1	=	10	=	0.39371
						1	=	0.03937

Measures of Capacity.

Liter.		Cubic Centimeters.		Pints.		Cubic Inches.
1	=	1000	=	1.76	=	61.0363
		1	=	0.00176	=	0.0610

Measures of Weight.

Kilogram.		Grams.		Lbs. (Avoirdupois).		Grains.
1	=	1000	=	2.2046	=	15432.00
		1	=	0.0022	=	15.432

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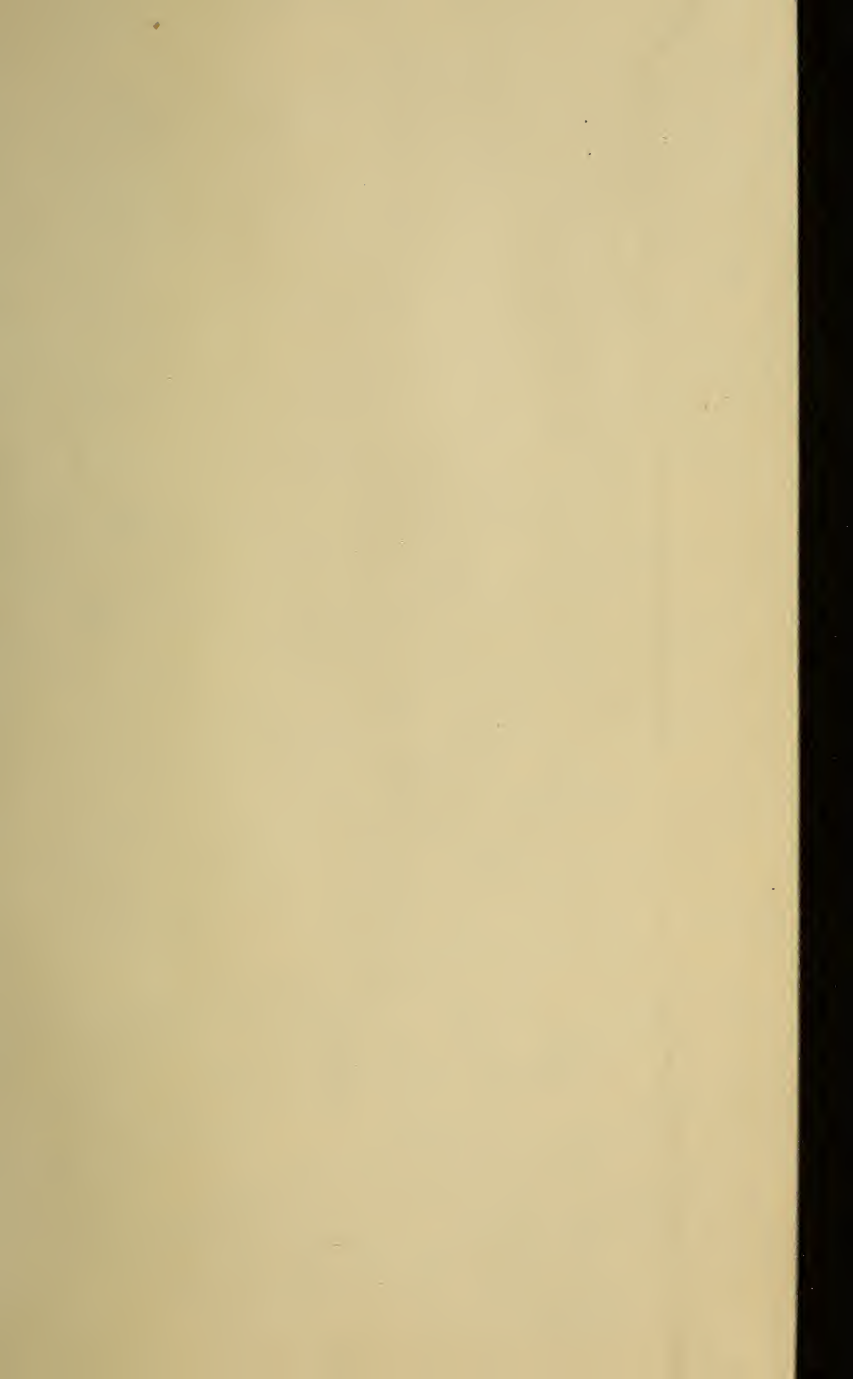
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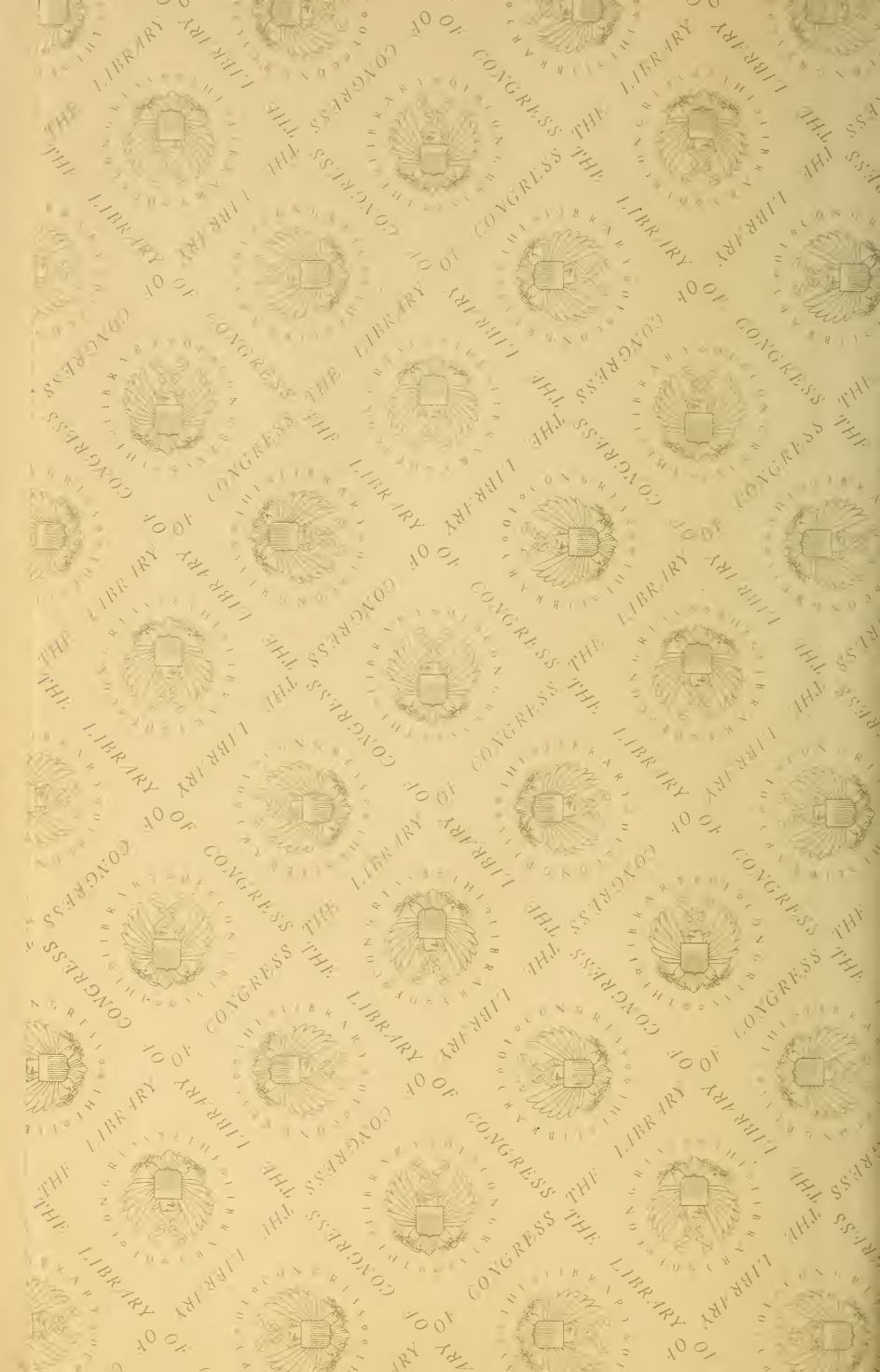
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